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TECHNICAL RELEASE NO. 78
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SUBJECT: ENG - THE CHARACTERIZATION OF ROCK FOR HYDRAULIC ERODIBILITY

Purpose. To transmit Technical Release (TR) No. 78: The Characterization of Rock for Hydraulic Erodibility.

Effective Date. When received.

This TR is intended to foster uniformity in the identification and acquisition of engineering geological field data and to provide guidance in the interpretation of rock material and rock mass properties that influence the hydraulic erodibility of rock in earth spillways. This document is a product of the emergency spillway performance study.

Filing Instructions. File with other technical releases.

Distribution. The distribution is shown on the reverse side and is based on the number of copies needed to provide one copy to each practicing professional engineer and geologist in each state and NTC. Additional copies may be obtained from the Consolidated Forms and Publications Distribution Center by ordering TR-78.

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DIST: TR-78

TECHNICAL RELEASE NO. 78

THE CHARACTERIZATION OF ROCK FOR HYDRAULIC ERODIBILITY

PREFACE

Scope

This technical release* is written for the Soil Conservation Service (SCS) **engineering geologist** to provide guidance in the identification and interpretation of rock material and rock mass properties that influence the hydraulic erodibility of rock in earth spillways, and to provide standard practices and terminology for measuring, describing, and documenting the engineering geological field data.

The engineering performance of an emergency spillway is a function of its resistance to hydraulic erosion. Thus, the costs associated with spillway design, layout, construction, operation, and maintenance are significantly affected by the character of earth materials encountered at a site. Recognition of the relevant geologic factors and their influence on erosion in spillways is essential to a design for passing the freeboard hydrograph without threatening the spillway integrity.

Although this technical release focuses on the assessment of rock for hydraulic erodibility, the described standard practices can be applied in other types of engineering performance assessments of rock, such as rippability, supportability, rock slope stability, and rock for construction, all of which may involve comminutive or exploitive processes controlled by the material and mass properties of the rock. This technical release may also have useful applications in the field of hydrogeology, particularly in water quality/quantity assessments which must address the movement of ground water and contaminants through discontinuities in rock.

Acknowledgments

This technical release is a product of the Emergency Spillway Flow Study Task Group (ESFSTG), which has conducted more than 100 spillway performance investigations over the period 1983 to 1990 (SCS, National Bulletins, 1984 - 1990), at sites that experienced conditions meeting or exceeding those described in the National Engineering Manual (NEM Section 504.11). This effort led to the devel-

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opment and analysis of a detailed geologic data base that provides the foundation for this technical release.

The team consists of John A. Brevard, Civil Engineer and team leader, SCS, National Headquarters (NHQ); John S. Moore, Engineering Geologist, SCS, Northeast National Technical Center (NNTC), Chester, PA; and Ray C. Riley, Hydrology Specialist, SCS, Stillwater, OK. Others who have served on the team include Louis Kirkaldie, National Engineering Geologist, SCS (retired); Alan B. Colwick, Civil Engineer, SCS, Temple, TX; James L. Hailey, State Hydrologist, SCS, Temple, TX; and Kerry D. Cato, Engineering Geologist, formerly SCS (part-time), currently with Ebasco Services, Inc., Greensboro, NC. James B. Hyland, National Engineering Geologist, SCS, NHQ; and David C. Ralston, National Design Engineer, SCS (retired), NHQ have made significant contributions to the study and have provided overall technical leadership to the team. The team has immeasurably benefitted from the mutual interest, support, and time of many professionals from the COE, Waterways Experiment Station, Vicksburg, MS, and the US Agricultural Research Service (ARS), Plant Science and Water Conservation Laboratory, Stillwater, OK, particularly Darrel M. Temple, Research Hydraulic Engineer, whose many contributions have been invaluable.

Parts of this document can be traced to the work of Robert F. Fonner, Engineering Geologist, SCS (retired), who wrote the first edition of Northeast Technical Service Center (NETSC) Technical Note 25 (TN-25), "Bedrock Classification for Excavated Rock Spillways," in 1978. TN-25 was subsequently revised by Louis Kirkaldie in 1981 and then superseded by NNTC TN-4 (Moore and Hall, 1987), "Excavated Rock Spillway Classification and Layout." The first national SCS document to substantively address rock mass characteristics was TR-71 (SCS, Feb, 1987), "Rock Material Field Classification Procedures", by Louis Kirkaldie; Douglas A. Williamson, Engineering Geologist, USFS; and Peter V. Patterson, former SCS National Engineering Geologist. This technical release supports and supplements table 1, Erosion Resistance, in TR-71.

This technical release uses terminology, practices, and descriptors from the following sources: American Society for Testing and Materials (ASTM); International Society for Rock Mechanics (ISRM); American Geological Institute (AGI); Geological Society of London (GSL); and Federal agencies involved in construction of dams, including the US Forest Service (USFS), the Bureau of Reclamation (BuRec), the US Army Corps of Engineers (COE), and SCS.

Purposes

The purposes of this technical release are to:

(1) identify geologic factors, particularly rock material and rock mass properties, that influence hydraulic erodibility of rock in earth spillways;

(2) provide guidance in predicting the influence of these factors on the engineering performance of rock in earth spillways; and

(3) foster continuity both within a project and across the agency by providing standard practices and terminology for measuring, describing, and documenting geological field data for planning, design, construction, or maintenance-related investigations of earth spillways.

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In order to use rock in engineering applications, certain properties of the rock must be assessed to reasonably predict performance in the as-built condition. The properties of rock fall into two broad classes: (1) Rock Material Properties* relating to the intact rock material itself, and (2) Rock Mass Properties relating to the in-place rock mass, including its system of discontinuities. This technical release addresses the properties of rock that are essential in assessing its hydraulic erodibility.

ROCK MATERIAL PROPERTIES

Rock material properties that are essential in assessing hydraulic erodibility of rock include rock type, color, particle size, texture, hardness, and strength. The identification and engineering significance of these properties are presented in chapter 3, Rock Material Properties. Seismic velocity, weathering, and secondary cavities are properties related to both the rock material and the rock mass and are presented in chapter 6. Rock material properties can be described in the field using qualitative methods and simple classification tests, or, if necessary, in the laboratory using standardized tests. The results are applicable to hand-specimens and representative samples of intact rock material.

ROCK MASS PROPERTIES

Rock mass properties that are essential in assessing hydraulic erodibility of rock are comprised of features generally observed, measured, and documented in the field on a macroscopic scale. Within a few hundred meters of the Earth's surface, discontinuities are the most universally occurring features in all rock masses; many are too large to be observed directly in their entirety at a single outcrop.

Discontinuities, in essence, are distinct breaks or interruptions in the integrity of a rock mass that convert a rock mass into a discontinuous assemblage of blocks, plates, or irregular geometric forms, called discrete rock particles. Thus, a discrete rock particle is an intact fragment of rock material whose shape and size are initially defined by the discontinuities that form its margins. Discrete rock particles may occur (1) in their place of origin, such as fractured, broken, or jointed in-situ rock, where particles retain their original form and size; or (2) away from

* **Note:** Terms that are defined in the Glossary (Appendix 1) are double underlined where first used in this technical release.

their place of origin with subsequent modification of size and shape occurring in the transport process. Naturally occurring examples include stream cobbles, talus, and glacial boulders; or they can be manufactured, as in the case of quarried rock. This release discusses discrete rock particles as they occur in their place of origin at the rock mass.

The properties of a rock mass are significantly different from the properties of intact rock samples of the same rock mass. The strength and mechanical behavior of the rock mass are commonly dominated by the nature of its mass properties than by its material properties. A rock mass comprised of even the strongest intact rock material is greatly weakened by the occurrence of closely spaced discontinuities. Material properties, on the other hand, tend to control the strength of the rock mass if discontinuities are widely spaced or if the intact rock material is inherently weak or altered. Thus, discontinuities within a rock mass reduce its strength and stability and reduce the energy required to excavate or erode it.

It is important to recognize that many rock properties interact under performance conditions. A performance assessment for any given engineering application must be viewed in the broader context of these interactions. The assessment includes the measurement, documentation, and interpretation of the behavior of a substance that is typically complex and anisotropic.

Types of Discontinuities

The term "discontinuity" applies to any distinct break or interruption in the integrity of a rock mass. In this technical release, discontinuities are classified according to their mode of formation, as either stratigraphic (chapter 4) or structural (chapter 5).

Stratigraphic Discontinuities.--Stratigraphic discontinuities originate at the time a rock mass is formed. These features apply to all stratified sedimentary rocks, most volcanic rocks, and some low grade metamorphic rocks. Two broad categories of stratigraphic discontinuities are considered in this technical release: the lithosome (depositional contacts) and the unconformity (erosional contacts). Zones of weathering or alteration may also be considered discontinuities.

Structural Discontinuities.--Structural discontinuities develop after the initial formation of the rock mass as a result of external processes acting on the rock mass. These features are produced by the mechanical deformation or displacement of rock by natural stresses within the Earth's crust. They include fractures of all types, planes or zones of weakness, shear/faults, and shear/fault zones, most of which have little to no tensile strength. The deformation of rock falls into three broad categories: elastic, plastic, and fracture deformation.

Elastic deformation is deformation from which the rock mass instantaneously recovers its original shape upon removal of the external forces acting on the rock mass. The passage of earthquake waves or tidal stresses may cause elastic deformation. Since no permanent structural discontinuities are produced by elastic deformation, this technical release addresses discontinuities associated only with plastic and fracture deformation.

Plastic deformation is deformation which exceeds the strain limit for elastic deformation and results in a permanent change in shape of the rock mass without loss of cohesion. Changes produced under these conditions include folds; foliation, such as schistosity and gneissosity; and other linear and planar structures. The orientation of such features is related to flowage and grain rotation accompanying compression and shearing forces. Certain stress fields may also favor the development of a preferred crystallographic orientation of the mineral grains; the orientation defines the texture of a metamorphic rock (Ernst, 1969).

Fracture deformation is deformation characterized by loss of cohesion and rupture of the rock mass. Rupture produces many types of discontinuities, such as faults, joints, and cleavage. Fractures not only disrupt the physical integrity of a rock mass, they intensify the influence of weathering processes that act to further weaken the rock mass over time. Caves and solution features are examples of chemical weathering processes exploiting joint systems in karst limestone terrain (see section on Weathering in chapter 6).

CHAPTER 2. ROCK CHARACTERIZATION IN EARTH SPILLWAYS

An earth spillway must be able to convey the freeboard hydrograph without threatening the integrity of the spillway. An earth spillway is designed, in part, on the erodibility of the earth materials that form its boundaries: the greater the erodibility, the wider the spillway, the flatter the exit channel slope, and/or the smoother the transition from the outlet channel to the floodplain.

CLASSIFICATION OF ROCK IN EARTH SPILLWAYS

Differentiation of earth materials into the subsets of "soil" and "rock" on the basis of geologic origin alone has led to confusion with standard engineering definitions of the terms (as defined in ASTM, 1986). The engineer is usually more interested in the performance of a material than its geologic origin. The geologist who maps a spillway site must draw from the fields of structural geology and stratigraphy where the emphasis and approach are clearly genesis-oriented. Determining the origin of geologic discontinuities can be useful in the interpretation of the size, shape, and lateral extent of a rock unit. Although a material's geologic origin and post-depositional history are extremely important in interpreting its structure and composition, a classification based on geologic origin alone may not reliably predict performance (Cato, Moore, and Kirkaldie, 1989). Examples of this dilemma include a re-cemented residual "soil" that can have the strength and erosion resistance of moderately soft rock (SCS, Feb. 18, 1987); conversely, some materials, such as friable, weathered shales that classify geologically as "rock," can erode as easily as some soils (SCS, Feb. 8, 1990).

To be classified as rock material in an earth spillway, the earth material of the mass in question must meet both of the following conditions:

Condition 1: the material must have an unconfined (uniaxial) compressive strength equal to or greater than 1.25 MPa*; and

Condition 2: more than 75 percent of the mass must consist of discrete rock particles with a mean diameter equal to or greater than 0.20 meter.

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* 1.0 megapascal (MPa) equals approximately 145 pounds per square inch (psi). 1.0 pascal (Pa) is equivalent to 1.0 Newton per square meter (N/m^2).

Classification Condition 1

Classification Condition 1 addresses the material strength of the rock. Rock material strength is a useful parameter in differentiating soil and rock materials for engineering purposes. Although unconfined or uniaxial compressive strength of intact rock material is determined by standardized laboratory testing, strength can be reasonably estimated in the field by using simple, empirical tests for rock hardness.

The range in strength of earth materials is a broad continuum spanning at least five orders of magnitude (see table 5). The strength value of 1.0 MPa is often recommended in the technical literature as a convenient transition point between soil and rock (e.g., Johnson and DeGraff, 1988; Bieniawski, 1989). The Geological Society of London, Group Working Party (1977), however, suggests a transition point of 1.25 MPa to move the strength value away from earth material strength associated with materials having the engineering properties of both soil and rock; hence the recommended value is 1.25 MPa. Earth materials with strength values less than 1.25 MPa are described according to standard soil mechanics practices and test methods. For a comparison of 11 hardness classifications of intact rock, see appendix 5.

The unconfined compressive strength of a specimen of intact rock material from a spillway site is, however, an inadequate measure of the strength of the overall rock mass. When considered at the scale for earth spillways, the strength of a rock mass is invariably less than its material strength owing to the effects of discontinuities within the rock mass.

Classification Condition 2

Classification Condition 2 addresses the integrity of the rock mass which is largely governed by the character of the discontinuities within the mass. Discontinuities reduce the strength of the rock mass and its resistance to erosion. For erosive forces encountered in spillways, a rock mass begins to emulate conditions for movable channel boundaries when the three dimensional spacing of the discontinuities produces discrete rock particles with mean diameters less than approximately 0.20 m. For smaller particles, bedload transport concepts apply in channel design. The 0.20 m value is the transition point between moderately wide and moderately close joint set spacings (see table 8, Spacing categories for bedding plane partings and joint sets).

Example 1

A spillway is underlain by granite with an unconfined compressive strength of 200 MPa and three mutually perpendicular, intersecting, open joint sets that are less than 0.15 m apart. The granite does not meet the criteria for rock because the mean diameter of discrete particles is less than 0.20 m. The channel surface is comprised of discrete blocks of granite material which may act as a movable boundary when subjected to hydraulic forces.

Example 2

A spillway is underlain by soft shale with a strength of 3 MPa; two intersecting joint sets, one spaced 3.0 m apart and the other spaced 2.0 m apart; and bedding plane partings spaced 50 mm apart (very thinly bedded). The shale in this spillway classifies as rock because the mean discrete rock particle diameter (the cube root of the product of the three dimensions, 0.67 m) is greater than 0.20 m, and because the strength is greater than 1.25 MPa. In determining the design and layout of the spillway, the designer will still need to consider the structural and stratigraphic characteristics that may affect spillway performance.

HYDRAULIC EROSION OF ROCK

For engineering performance, the ideal rock in an excavated spillway is everywhere uniform, stable, and unmovable during passage of the freeboard hydrograph. Natural rock, however, is not uniform at the dimensions needed to build a spillway. In fact, a rock mass is inherently variable because of the widespread occurrence of discontinuities, changes in composition (rock type), and weathering characteristics. The erodibility of rock is influenced by many interrelated geologic factors including material properties of the rock itself, as well as characteristics of the rock mass, particularly structural and stratigraphic discontinuities which determine the overall integrity of the rock mass. The hydraulic erodibility of rock is also a function of the hydraulic conditions during flow, including flow depth, velocity of flow, duration of flow as determined by the shape of the outflow hydrograph (discharge-time relationships). It is also a function of the layout of the spillway, including the difference in head (elevation) between the crest of the emergency spillway and the end of the exit channel, and of the length of the exit channel.

Large-scale discontinuities, as opposed to microscopic, grain-to-grain discontinuities, are responsible for the most adverse channel responses to emergency spillway flow in rock spillways (Cameron, et. al., 1988). Discontinuities in earth materials tend to control the location, development, and geometry of knickpoints during spillway flow by affecting channel hydraulics. Portions of spillway flow can be redirected and concentrated by discontinuities resulting in the formation of gullies or scour holes that can migrate toward the control section. Knickpoints can rapidly develop into steep, vertical, or overhanging waterfalls, or a series of "stairstep" falls. A knickpoint tends to be a short lived feature whose position and geometry vary according to flow conditions, especially discharge and duration of flow (Cameron, et. al., 1988). Thus, the development and upstream migration (also called "headcutting") of knickpoints depend upon the relative erosion-resistance of channel materials and their response to discharge conditions. Other critical areas subject to erosion by concentrated or redirected emergency spillway flow include the exit channel retaining dikes and the toe of the embankment.

Flow concentrations can occur at the following places: (1) at abrupt gradient changes in the channel profile (such as from gentle to steep/vertical grades, or from steep to gentle grades), where hydraulic jumps can cause highly erosive turbulence; (2) on the outside of curves in the channel; (3) at non-uniform or uneven areas in the channel floor, caused by poor quality construction, vehicle ruts, cattle paths, and other such depressions; and (4) at changes in the continuity of the rock mass. The first three are design, construction, and operation and maintenance considerations that are beyond the scope of this technical release; the fourth is a topic of this technical release.

INTENSITY OF GEOLOGIC INVESTIGATION

General

Requirements for geologic investigation for design and construction purposes vary according to the site and must be consistent with policy set forth in the National Engineering Manual, Part 531.03, Minimum Requirements (SCS, Oct, 1986). In NEH-8, chapter 5, Requirements for Geologic Investigations and Sampling (SCS, 1978), dam sites are grouped according to size and purpose of structure, economic and safety considerations, and geologic complexity of the site. There are two levels of intensity of geologic investigation: the subjective assessment and the objective assessment.

Before initiating either type of assessment, the investigating geologist must study all available, pertinent technical resources, such as regional geologic maps, published and unpublished reports, topographic maps, site surveys, aerial photographs, soil survey reports, geotechnical maps and reports of the site or similar sites; and inspect the outcrops in the vicinity of the site in order to become familiar with the major structural features and dominant rock types. Ascertaining the structural domain will aid the engineering geologist in deciding on the appropriate level of intensity needed to assess the properties of the rock.

Subjective Assessment

A subjective assessment of rock mass and rock material properties involves the use of relatively simple field tests and procedures. This approach is usually adequate at a site situated in a structural domain with regional discontinuity trends that are readily apparent or can be adequately distinguished using statistical techniques (for guidance, see appendix 2, The Fixed Line Survey) with a reasonable number of observations (Prokopovich, 1972). Although the subjective survey is generally adequate at most Group II or Group III dam sites, the occurrence of complex or otherwise significant discontinuities may dictate the application of an objective survey to improve the characterization of the site geology.

Objective Assessment

An objective assessment is a detailed assessment of rock mass and rock material properties at a site situated in a complex structural domain where discontinuity patterns are not readily apparent. The geologist systematically evaluates all the discontinuities in the rock mass exposed within a fixed area at the site. The objective approach requires considerably more time and effort than the subjective approach. The objective assessment reduces the risk of overlooking or discounting discontinuities and other features of the rock which might be important. Although this type of assessment is especially suitable for Group I dams, it can be used for any site investigation requiring refined characterization, such as spillway performance investigations.

PRESENTATION OF DATA

Uniformity in the identification and description of rock properties is essential in maintaining continuity in geologic logs, drawings, and reports. Data must be documented and presented in a form that can be readily understood and interpreted by others involved in the investigation, design, construction, and maintenance of the spillway. The need for continuity is especially apparent for projects with several levels of investigation or different investigators. Using standard practices, definitions, and descriptors will provide the needed uniformity within any given project as well as across the agency as a whole.

Data must be recorded and presented in a way that conveys the most relevant and dependable information. For convenience, all the tables in this technical release are consolidated in abbreviated form into the Rock Description Data Sheets and the Discontinuity Survey Data Sheets in appendix 6. The investigating geologist should photocopy these sheets on an as-needed basis and use them to ensure that all essential data are gathered.

CHAPTER 3. ROCK MATERIAL PROPERTIES

ROCK UNIT IDENTIFICATION

Identify each rock unit at the site by either its proper formation name (e.g., St. Peters Sandstone) or by an alpha-numeric designation (e.g., Rock Unit L-6), whichever is the most useful. If a formation has multiple beds or units of differing engineering behavior, the alpha-numeric designation is preferable (TR-71, SCS, Feb 1987).

Describe the location of each rock unit by station, elevation, and position in the stratigraphic section. Indicate its location and extent on a geologic evaluation map (GEM) of the spillway site.

ROCK TYPE

Definition

Rock type is a simplified geologic classification of rock based on its genetic category, structure, composition, and grain size.

Background

Table 1 gives the rock type classification modified from one developed by Dearman (*in*, GSL, 1977). This classification uses primarily common rock type names that can be assigned in the field without need for detailed lab tests or thin sections.

Identification

The equipment needed to identify rock type include a geologist's hammer with pick end, 10x hand lens, hydrochloric acid (10 N solution: 1 part acid to 3 parts distilled water), pocket knife, 15 cm (6-inch) scale, AGI Data Sheets.

Using standard field identification procedures and table 1 as a guide, classify all identified rock units and record the rock type name and two-digit code number for each unit on a Rock Description Data Sheet.

Use more detailed mineralogical and fabric descriptors only if they are needed for correlation purposes or are germane to engineering properties of the rock. Use common terminology, such as "schist," instead of technically correct, but jargon-rich terms, such as

TABLE 1.—ROCK TYPE CLASSIFICATION

Genetic Group	Predominant Grain Size, mm (Sieve No.)	Detrital Sedimentary			Chemical/ Organic	Metamorphic		Pyroclastic	Igneous			
Usual Structure		Bedded			Bedded	Foliated	Massive	Bedded	Massive			
Composition			Grains of rock, quartz, feldspar, and clay minerals	At least 50 % of grains are of carbonate	Salts, carbonates, silica, carbonaceous	Quartz, feldspars, micas, dark minerals	Quartz, feldspars, micas, dark minerals, carbonates	At least 50 % of grains are of igneous rock	Quartz, feldspars, micas, dark minerals		Feldspar; dark minerals	Dark minerals
									Acid	Intermediate	Basic	Ultrabasic
Very Coarse-grained		Rudaceous	Grains are of rock fragments Rounded Grains: CONGLOMERATE (11)	LIMESTONE (undifferentiated) (21) CALCIRUDITE (23)	CLINKER (31) SALINE ROCKS Halite (32)	TECTONIC BRECCIA (41) MIGMATITE (42)	METACONGLOMERATE (51)	Rounded grains: AGGLOMERATE (61)	PEGMATITE (71)			
Coarse-grained	75 (3")		Angular grains: BRECCIA (12)		Anhydrite (33) Gypsum (34)	GNEISS (43)	MARBLE (52)	Angular grains: VOLCANIC BRECCIA (62)	GRANITE (72)	DIORITE (81) GRANODIORITE (82)	GABBRO (91)	PYROXENITE (01)
Medium-grained	4.75 (4)	Arenaceous	Grains are mainly mineral fragments SANDSTONE (13) ARKOSE (14) GRAYWACKE (Argillaceous ss) (15)	CALCARENITE (24)	CALCAREOUS ROCKS	SCHIST (44)	GRANULITE (53) QUARTZITE (54)	TUFF (63)	SYENITE (73)	ANORTHOSITE (83)	DIABASE (92)	PERIODTITE (02)
Fine-grained	0.074 (200)	Argillaceous or Lutaceous	MUDSTONE (16) SHALE: fissile mudstone (17) SILTSTONE > 50 % fine-grained particles (18)	MARLSTONE (22) CALCI-SILTITE (25)		AMPHIBOLITE (45) PHYLLITE (46)		Fine-grained TUFF (64)	APLITE (74)	MONZONITE (84) DACITE (85)		
Very Fine-grained	0.005		CLAYSTONE > 50 % very fine grained particles (19)	CHALK (26) CALCILUTITE (27)	Limestone (35) Dolomite (36)	MYLONITE (47) SLATE (48)	HORNFELS (55)	Very fine-grained TUFF (65)	RHYOLITE (75)	ANDESITE (86)	BASALT (93)	DUNITE (03) NEPHALINE-BASALT (04)
Glassy Amorphous					SILICEOUS ROCKS Chert (37) Flint (38) CARBONACEOUS ROCKS Lignite/ Coal (39)	ULTRAMYLONITE (49)		Welded TUFF (66) PUMICE (67)	VOLCANIC GLASSES OBSIDIAN (76)	PITCHSTONE (87)	TACHYLYTE (94)	

Note: code number in parentheses is used in sheet 1 of 3, Rock Description Data Sheets "albite-epidote-amphibolite-schist." If more detailed guidance is required, refer to the AGI (1989) Data Sheets or Travis (1955).

Engineering Significance

Geologic names of rocks are intended to classify rocks according to their modes of origin. Although the geologic classification may not always relate directly to engineering properties of rock, it is indispensable for identification purposes and may be useful for correlation with outcrops outside of the project area.

Rock type also provides some indication of the processes which acted on the rock during and after its formation; these facts may be valuable in predicting the size, shape, extent, and location of beds, lenses, and stringers that could serve as discontinuities. Rock type can indicate mineralogical and textural characteristics which may provide insight into the physical and chemical interaction between the grains. An example is granite, which by definition is an igneous rock that forms by slow cooling at depths where the confining pressures may exceed 1000 MPa. Consequently, some near-surface or exposed granites form horizontal stress relief fractures in response to the reduced confining pressures associated with the geologic erosion of overlying materials.

Information provided by the accessory minerals in the name of a rock can provide clues to properties that have engineering significance. For example, a mica schist might indicate potentially weak rock because the sheet silicates (the micas and chlorite) impart low shear strength to the rock mass (Goodman, 1976).

COLOR

Definition

Color is an attribute of visual perception that can be described by color names (ASTM, 1986).

Background

Color is difficult to describe because a perceived color greatly depends not only on the spectral power distribution of the color stimulus, but also on the size, shape, structure, and envelop of the stimulus area. For example, a given color will appear differently when seen next to other colors; grey appears bluish when seen next to orange or brown earth colors (Compton, 1985). Perceived color also depends upon the observer's experience with similar observations; hence, a color may often be named differently by different persons.

The most widely accepted system of color notation in the United States is the Munsell Soil Color Charts. This system provides a detailed coverage of colors for soil, sediments, and most rocks (available from Munsell Color Company, 2441 N. Calvert St., Baltimore, MD 21218). A broader, but less detailed chart is given in the Rock Color Chart from the Geologic Society of America (PO Box 9410, Boulder, CO 80301). For rapid field logging purposes, e.g., reconnaissance investigations, table 2 can be used as an alternative.

Table 2.--Rock color (modified after GSL, 1977)

1	2	3
light	pinkish	pink
dark	reddish	red
	yellowish	yellow
	brownish	brown
	orange	orange
	olive	olive
	greenish	green
	bluish	blue
		purple
		white
		buff
	greyish	grey
		black

Identification

When using table 2, a color from column 3 can be supplemented, if needed, with a term from column 2, column 1, or both. Terms such as banded, mottled, streaked, speckled, and stained may be used as modifiers.

Record the color of each rock unit in both its wet and dry states. Indicate whether the sample was in a fresh or altered condition since these conditions can affect color.

Engineering Significance

Color can be an indication of the weathered state of the rock. Discoloration of rocks to shades of red, yellow, orange, and brown is indicative of leaching of iron, Fe^{++}, from unstable minerals and its fixation as Fe^{+++} in oxide pigments. The degree of discoloration thus provides an indication of the degree of stability of minerals in rocks (Compton, 1985).

Color changes may be indicative of changes in the mineral assemblage, texture, organic carbon content (shales), or other properties. Color may also reflect the provenance of sediments.

Color is very useful in correlation since it is readily observed.

PARTICLE SIZE/TEXTURE

Definitions

Particle size refers to the size of the particles that make up a sedimentary or pyroclastic rock.

Texture refers to the crystallinity and granularity of igneous and crystalline metamorphic rocks.

Background

The particle sizes used in the description of rocks for engineering purposes should be consistent with those used for soils (ASTM: D-422-63 [1972], D-2488-84, and D-653-88). The format of Table 3 is modified after BuRec (1989) and GSL (1977). The lithified product is the name for the equivalent sedimentary or pyroclastic particles after lithification of the material.

Identification

A hand lens is usually sufficient to ascertain rock particle size and rock texture. In rare instances, a thin-section may be needed.

For sedimentary and pyroclastic rock types, use the rock particle size descriptors given in table 3. Record the particle size or lithified product of each rock unit and the descriptive system used.

For each igneous or crystalline metamorphic rock unit, record the rock texture using the descriptors in table 4 as a guide. Refer to the AGI Data Sheets if more detailed descriptors are needed.

Table 3.—Particle-size Descriptors for Sedimentary and Pyroclastic Rocks

Descriptive Term (Rocks)	Descriptive Term, (USCS, soils only)	Particle Size mm	(inches)	sieve	Sedimentary (Rounded, subrounded, subangular, angular) Particle or Fragment	Sedimentary Lithified Product	Volcanic (pyroclastic) Fragment	Volcanic (pyroclastic) Lithified Product
Very Coarse-grained	Boulder				Boulder	Boulder conglomerate	Block	Volcanic breccia (Angular grains)
	Cobble	300	(12)					
		256	(10)		Cobble	Cobble conglomerate	Bomb	Agglomerate (rounded grains)
Coarse-grained	Coarse gravel	75	(3)					
		64	(2.5)		Pebble	Pebble conglomerate	Splatter	Agglutinate
		32	(1.3)				Lapillus	Lapillistone tuff
	Fine gravel	20	(0.8)					
Medium-grained	Coarse sand	4.75	(0.19)	4				
		4	(0.16)		Granule	Granule conglomerate	Coarse ash	Coarse tuff
	Medium sand	2	(0.08)	10	Very coarse sand	Sandstone (Very coarse, coarse, medium, fine or very Fine)		
		1	(0.04)		Coarse sand			
		0.5	(0.02)		Medium sand			
	Fine sand	0.42		40				
		0.25			Fine sand		Fine ash	Fine tuff
		0.125			Very fine sand			
Fine-grained	Fines Nonplastic Silt / Plastic Clay	0.074		200				
		0.0625			Silt	Siltstone or Silty shale		
Very Fine-grained		0.005			Clay	Claystone or Clay shale		

Table 4.--Texture descriptors for igneous and crystalline metamorphic rocks

1. Aphanitic (syn.: cryptocrystalline, or microcrystalline)--crystalline components cannot be seen with the naked eye.
2. Crystalline--composed entirely of contiguous or interlocking crystals.
3. Glassy (syn.: vitreous)--for certain extrusive igneous rocks that cooled rapidly, without distinct crystallization.
4. Pegmatitic--very coarse-grained, crystals >10 mm in diameter.
5. Porphyritic--large crystals set in a fine-grained ground mass that may be glassy or crystalline.

Engineering Significance

Depending on the strength of the bonding between the particles that constitute the rock material, particle size and texture can be determining factors in the size of the rock products derived by mechanical or chemical weathering of the rock, particularly in the sand, gravel, and larger size ranges.

HARDNESS

Definition

Hardness is the subjective description of the resistance of an earth material to permanent deformation, particularly by indentation (impact) or abrasion (scratching) (ASTM, 1986).

Background

There is no absolute scale for hardness because it is not a material property, strictly speaking (ISRM, 1981). It is erroneous to apply the Mohs Hardness Scale in describing rock hardness. The Mohs scale is a qualitative scale for a set of empirical tests used to differentiate minerals in hand specimen by scratching. **The scale has no useful application in describing most rock material for engineering purposes because most rock types are aggregates of more than one mineral.**

Hardness is simply a qualitative expression of earth material strength; the hardness categories form a scale of ranges in strength values obtained from the laboratory test for strength (see section on STRENGTH). To determine the range in strength values for each hardness class in the SCS hardness scale (NEH-8, p. 1-13), several empirical classifications of rock hardness were reviewed (see Appendix 5 for a comparison of 11 hardness scales). The strength values used by the Geological Society of London (1977) is recommended for differentiating the SCS hardness classes because the subjective field tests for both systems are similar.

For evaluation of excavation characteristics and hydraulic erodibility of rock and for classifying rock for excavated auxiliary spillways, the field tests for rock hardness given in Table 5 will provide a reasonable strength estimate. The field tests are rapid and easy to use. The greater accuracy attained by the more laborious laboratory strength test seldom improves interpretation because large differences in strength are required to significantly affect rock performance. It is therefore not essential to know the strength of rock material with great accuracy. Laboratory testing may be conducted periodically as an aid to correlation of field tests, but this will rarely be necessary.

Identification

The equipment needed to perform the field tests for hardness include a pocket knife, a geologist's hammer with pick end, and a common 20d steel nail.

For each rock unit, determine the hardness category by using the field tests given in Table 5. Optional methods for determining rock hardness include:

(1) ASTM D 5873, Standard Test Method for Determination of Rock Hardness by Rebound Hammer Method--applies for rocks that have hardnesses between the very soft and very hard categories. In use, this instrument (also called a rock classification hammer) is pressed against the rock surface until a spring-loaded hammer impacts automatically. The rebound intensity gives a measure of compressive strength (ISRM, 1981, pp.101-102).

(2) The Pocket Penetrometer--is used to classify hardness of earth materials that have strengths less than 2.00 MPa (soft rock category or softer).

Record the measured value and hardness category of each rock unit using Table 5 as a guide.

Table 5: Correlation of Earth Material Hardness Categories with Laboratory Uniaxial Compressive Strength (after GSL, 1977; ISRM, 1981, and Kirsten, 1988)

Earth Material Hardness Category	Uniaxial Compressive Strength (MPa)	Field Tests for Estimating Hardness
Very soft soil*	< 0.04	Exudes between fingers when squeezed in hand. Easily penetrated several centimeters with fist.
Soft soil*	0.04 - 0.08	Easily molded with fingers. Pick head of geologic hammer can easily be pushed in to shaft of handle.
Firm soil*	0.08 - 0.15	Can be penetrated several centimeters by thumb with moderate pressure. Molded by fingers with some pressure.
Stiff soil*	0.15 - 0.30	Indented by thumb with great effort. Point of geologic pick can be pushed in up to 1 cm. Very difficult to mold with fingers. Can just be penetrated with hand spade.
Very stiff soil*	0.30 - 0.60	Indented only by thumbnail. Slight indentation produced by pushing point of geologic pick into material. Requires hand pick for excavation.
Very soft rock (or hard, soil-like material)	0.60 - 1.25	Can be scratched with fingernail. Slight indentation produced by light blow of point of geologic pick. Requires power tools for excavation. Can be peeled with a knife.
Soft rock	1.25 - 5.0	Hand-held specimen crumbles under firm blows with point of geological pick.
Moderately soft rock	5.0 - 12.5	Shallow indentations (1 to 3 mm) can be made by firm blows with point of geological pick. Can be peeled with pocket knife with difficulty.
Moderately hard rock	12.5 - 50.0	Cannot be scraped or peeled with pocket knife. Intact hand-held specimen can be broken with a single blow of hammer end of geologic pick. Can be distinctly scratched with a steel nail.
Hard rock	50.0 - 100.0	Intact hand-held specimen requires more than one hammer blow to break it. Can be faintly scratched with a steel nail.
Very hard rock	100.0 - 250.0	Intact specimen breaks only by repeated, heavy blows with geologic hammer. Cannot be scratched with a steel nail.
Extremely hard rock	> 250.0	Intact specimen can only be chipped, not broken, by repeated, heavy blows of a geological hammer.

<u>Notes</u>:

(1) Hardness categories are based solely on hardness characteristics rather than on geologic origin. For examples, some highly weathered shales may classify as Firm Soil, while some partially lithified Recent soils may classify as Moderately Soft Rock. The transition, however, more commonly occurs in the 0.60 to 1.25 MPa range.

(2) Materials marked with (*) must be evaluated for hardness in the wet condition and are assumed to be cohesive.

(3) 1.0 Megapascal (MPa) approximately equals 145 pounds per square inch (psi) or 10.4 tons per square foot (tsf). Vane shear strength is also applicable.

(4) Vane shear strength values are also applicable in the lower strength ranges.

Engineering Significance

The hardness of rock material is a function of the individual rock type but may be modified (weakened) by chemical or physical weathering (see section on WEATHERING, chapter 6).

Although hardness categories provide reasonable estimates of rock material strength, one of the two conditions used in classifying earth material as rock in excavated emergency spillways, the designer must carefully consider the characteristics of the rock mass before reaching a decision on alignment and location of a rock spillway.

Key areas of the spillway where the hardness (strength) of earth materials need to be carefully documented and evaluated include the area below the longitudinal bulk length, particularly the control section, to a minimum depth of 10 meters, and at abrupt gradient changes (breaks greater than 4°, as a rule of thumb) in the exit channel profile, where hydraulic jumps typically form. Abrupt grade changes are common where exit channels discharge onto hillslopes.

STRENGTH

Definition

Strength is the ability of a material to resist deformation induced by external forces. Thus, the strength of a material is the amount of applied stress at failure (ASTM, 1986). The laboratory uniaxial (unconfined) compressive strength has long been the standard strength parameter of intact rock material.

Background

Rock material strength is determined by standard laboratory test methods. Since large differences in strength are required to significantly affect excavation characteristics and hydraulic erodibility of rock, it is not essential to know strength with great accuracy. The rock hardness category will nearly always provide a reasonable estimate of rock material strength. The greater accuracy attained by laboratory testing will seldom improve prediction of rock performance. In most cases, lab testing will be unnecessary except as an aid in correlation of field tests.

Identification

If strength is to be determined by laboratory testing, the following methods may be used:

(1) ASTM D 4543: Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens;

(2) ASTM D 2938: Standard Practice for Preparing Rock Core Specimens and Determining Dimensional and Shape Tolerances; and

(3) ASTM D 5731: Standard Test Method for Determination of the Point Load Strength Index of Rock. This test method is a laboratory test that can also be conducted in the field. The test is sensitive to moisture variations of the samples. Because Point Load Test results are lower than Unconfined Compressive Strength Test results, the values are not directly correlative. According to ASTM D 5731, the point load index for NX (54 mm) core is equal to UCS divided by 24. For more discussion on point load strength, see Broch and Franklin (1972), Bieniawski (1975), and GSL (1977).

If strength is to be determined by correlating with hardness, use Table 5 as a guide. Record results and the test method used on the Rock Mass Description Data Sheets for each identified rock unit.

Engineering Significance

Rock material strength is one of two conditions used in classifying earth material as rock in earth spillways. For the purposes of this technical release, rock material strength can be reasonably estimated from the rock hardness scale (Table 5) without conducting a laboratory strength test.

It is important to recognize that **rock mass** strength is largely governed by the discontinuities within the mass; as the number of discontinuities decreases and spacing increases, the more closely the values for rock mass strength will agree with those of its intact rock material strength. The field strength of the in-situ rock mass will always be less than the laboratory strength of an intact sample of the mass.

Designers must bear in mind that rock material strength is always subordinate to the strength of the rock mass; rock mass strength depends greatly on the characteristics of its system of discontinuities. Refer to Chapters 4 and 5 for more information on discontinuities. As a rule, where rock is subject to hydraulic attack, weak rock with discrete particles having mean diameters greater than 0.20 m is preferable to strong rock having discrete particles less than 0.20 m in mean diameter.

CHAPTER 4. ROCK MASS PROPERTIES: STRATIGRAPHIC DISCONTINUITIES

LITHOSOMES

A lithosome is a rock unit of essentially uniform or uniformly heterogeneous lithologic character, having intertonguing relationships in all directions with adjacent masses of different lithologic character. Features that characterize a lithosome include the size, shape, and lateral extent of a rock unit that formed under uniform physico-chemical conditions.

In addition to sedimentary lithosomes, another variety includes discontinuities related to contact metamorphism. High temperature igneous magma may penetrate into sedimentary rocks (or other rock types), extrude onto the Earth's surface, or form an intrusive body at depth. Heat can reconstruct the mineralogical and textural makeup of the adjacent host rock creating a "baked" contact zone. The rock in this zone is commonly called hornfels, which is a dense, hardened, flinty, fine-grained material, sometimes with one or more minerals prominent as larger crystals. The width of the zone varies according to the size of the intrusion--from a featheredge around thin basaltic dikes and sills, to several kilometers in the case of large, granitic igneous plutons.

UNCONFORMITIES

An unconformity is a temporal break in the stratigraphic record caused by either non-deposition or geologic uplift and erosion. There are several types of unconformities, the present-day soil-rock interface being a common example. The engineering geologist is primarily concerned with those types that juxtapose earth materials of widely different engineering properties.

DISCUSSION

Because stratified sedimentary rock is so common throughout the United States, the identification of stratigraphic discontinuities in detailed engineering geological mapping is essential at many SCS spillway sites. Particular attention needs to be paid to sedimentary facies. Facies is the aspect, appearance, or attributes of a rock unit usually reflecting the conditions of origin of the rock unit. The conditions of origin include the energy environment of deposition, the provenance and availability of sediments, as well as the physical, chemical, climatological, and other environmental characteristics that prevailed during deposition and lithification. These factors collectively determine the size, shape, continuity, and vertical and lateral extent of the rock unit, and largely determine the properties of the sediments deposited in the environment.

The type of depositional environment within a sedimentary basin bears strongly on the development of stratigraphic discontinuities and the problems of correlation. Most continental and nearshore marine environments are characterized by highly variable energy conditions that result in abrupt facies changes. At the time of deposition, sediments have areal dimensions that are closely related to the depositing medium. For examples, stream and beach deposits are linear, running parallel to the stream flow or surf action. Deep-sea muds and lagoon sands will be widespread and blanket-like (LaPorte, 1968). Carbonate facies of some widespread, shallow water, marine environments can be so uniform in composition, thickness, and continuity that they can be traced for hundreds of kilometers with little variation.

Dikes and sills of igneous origin can be considered a type of lithosome or rock unit with engineering significance. These igneous bodies interrupt the continuity of the country (host) rock resulting in the juxtaposition of materials that may have widely different engineering properties affecting rock mass strength, erodibility, and excavatability. Dikes and sills can erode differentially; portions of the spillway flow can be expected to be redirected initially in the direction of the strike of the sill/dike; with continued flow and concomitant erosion and lowering of the local base level, erosion can be expected to proceed in the direction of dip.

IDENTIFICATION

The geologist must become thoroughly familiar with the literature pertaining to the field area before commencing the field investigation. The mapping effort will require good skills in identifying and interpreting sedimentary facies.

Using all available outcrop and subsurface data, prepare geologic maps, cross-sections, fence diagrams, or sketches, as appropriate, illustrating all significant stratigraphic discontinuities. Use conventional geologic symbols (refer to SCS Form 35-C; for additional standard symbols, follow the AGI, 1989, Data Sheets).

For each identified and mapped stratigraphic discontinuity, record whether the type is a lithosome or unconformity on the Discontinuity Survey Data Sheets.

For a lithosome, describe its shape using the descriptors in table 6 as a guide.

Table 6.--Descriptors for shape of lithosome

1. Blanket: a sheet-like, tabular body with one dimension considerably thinner or shorter than the other two dimensions. Syn.: seam.

2. Tongue: a prism or tongue-shape body with the shortest dimension thinning in one direction. Syn.: pinch-out; wedge.

3. Shoestring: one dimension is considerably larger than the other two; the term "columnar" is appropriate if the long dimension is vertical. Syn.: stringer.

4. Lens: a body with tapering edges.

5. Slump feature: a post-depositional slump, fold, or buckle produced by downslope movement of somewhat more competent layers which maintain their continuity and are not pulled apart or disrupted. Common in the thin-bedded, sand/shale sequences.

Record the location of the discontinuity by stationing and elevation. Measure and record the orientation of the discontinuity as an azimuth from true north and again as an azimuth with respect to spillway flow direction at that point in the spillway.

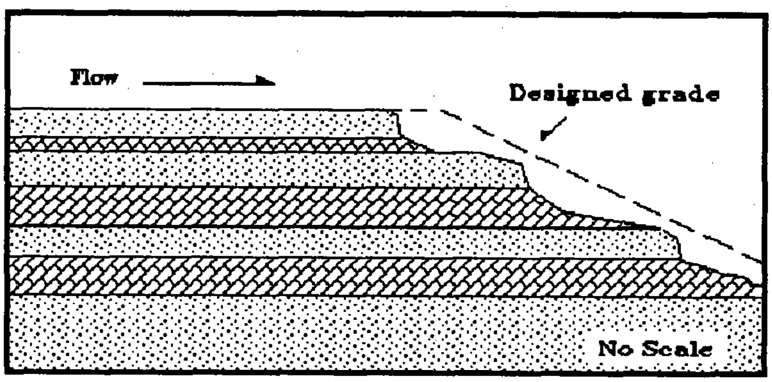
Most of the supporting documentation will consist of the maps, cross-sections, and sketches of the stratigraphic discontinuities.

ENGINEERING SIGNIFICANCE

Juxtaposition of geologic materials with widely different mechanical behavior and erodibility can result from abrupt lateral or vertical changes in composition, texture, or hardness associated with unconformities or variations in sedimentary facies. For example, interfingered thin seams and lenses of inherently weak materials such as bentonite or other expansive clay shales, calcite, gypsum, or organic shales in sedimentary rock masses can significantly increase the hydraulic erodibility of the rock. Thus, detailed mapping of the location, size, shape, continuity, orientation, and lateral extent of lithosomes and unconformities is essential for prediction of the locations of potential knickpoints, overfalls, and scour holes, particularly in exit channels that discharge onto steep hillslopes. The designer needs to know the location and erodibility characteristics of identified stratigraphic discontinuities.

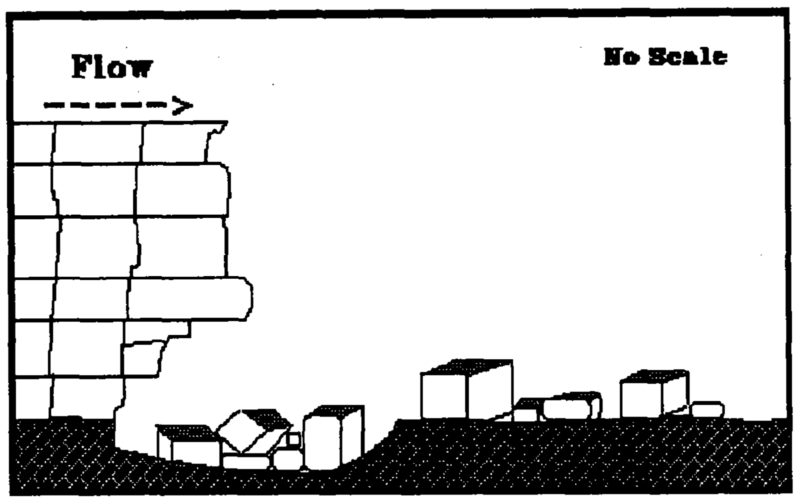
Many emergency spillway exit channels are designed with the outlets discharging onto significantly steeper, natural hillslopes where turbulence can form a headcut (usually a waterfall or scour hole). The headcut formation represents a transition from a condition of surface attack to an overfall condition (Temple, 1988). In flat-lying, alternating sequences of dissimilar rock types, such as sandstones and shales in beds of roughly equal thicknesses, erosion produces a "stairstep" pattern that results in a comparatively gradual dissipation of flow energy down the hillslope (figure 1).

Figure 1.--Stairstep erosion pattern in flat-lying rocks of variable resistance



When overlying resistant units are significantly thicker than underlying less resistant units, an overfall condition can develop. Less resistant units situated in the plunge area are subject to the full, undissipated attack of the spillway flow energy. As the underlying units are scoured out, the upper units become undermined and collapse, usually in large, discrete blocks (figure 2). Structural discontinuities (e.g., joints) in the upper unit control the size and shape of the eroded blocks. The process proceeds upstream, resulting in the headward migration of the overfall until either the resistant unit is lowered by collapse and removed or the flow stops (Cameron, et. al., 1988a).

Figure 2.--Undermined and collapsed rock

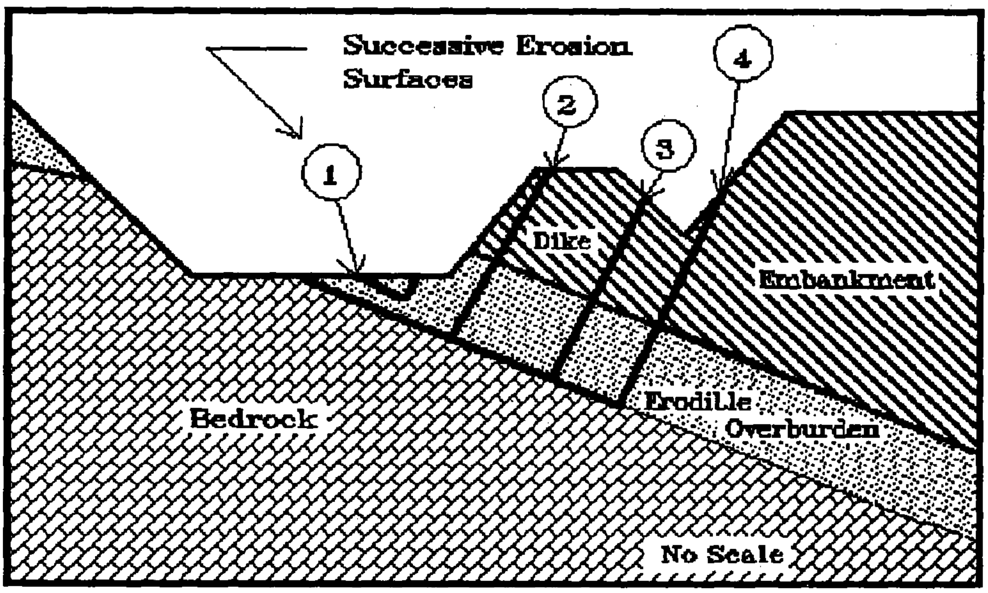


A common unconformity encountered at excavated emergency spillways, particularly in the exit channels, is the soil/rock interface. Ordinarily, the surface of the rock is approximately parallel with the slope of the valley wall and, therefore, slopes toward the dam.* Gullies typically begin either in the lower reaches of the constructed outlet channel or downstream below the constructed channel. Once initiated, gullies tend to migrate upstream toward the control section. Gullies form in the overburden materials that generally cover the surface of the rock. These materials may consist of natural colluvium, talus, residuum, alluvium, or man-made fill. Such materials are generally more erodible than the compacted materials of the dam or retaining dike. Once a downward-eroding gully encounters rock surface, the gullying process is

* Exceptions include sites located in areas of superposed drainage patterns where the slope of the rock surface (i.e., the configuration of the buried topography) bears no relationship to the surface topography.

forced to progress down the slope of the rock surface, which is toward the retaining dike or the dam. The concentrated flow in the gully then impinges upon and attacks the dike or dam (figure 3).

Figure 3.--Rock surface under spillway exit channel directs gullying toward dike and embankment



CHAPTER 5. ROCK MASS PROPERTIES: STRUCTURAL DISCONTINUITIES

DISCONTINUITIES RELATED TO PLASTIC DEFORMATION

Background

The types of discontinuities related to plastic deformation of rock that are considered in this technical release include all types of folded structures (including monoclines), foliation (gneissosity and schistosity), and banded rocks.

Folded Structures

A fold is a systematically curved layer or surface in a rock mass. Although any layered, banded, or foliated rock may display folds, they are most conspicuous in stratified sedimentary or volcanic rock formations or their metamorphosed equivalents. Folds are basic geologic structures; their shapes are endless in variety, and in size they may range from a few millimeters to hundreds of kilometers in wave length (the distance between adjacent crests of folds).

Foliation

Foliation is the planar arrangement of textural or structural features in any type of rock, although it is commonly associated with the planar or platy structure that results from flattening of the constituent grains of a metamorphic rock. A foliated rock tends to break along approximately parallel surfaces. Schistosity and gneissosity are the two main types of foliation.

Schistosity.--A type of foliation or cleavage formed by dynamic metamorphism resulting in a parallel, planar arrangement of mineral grains of the platy, prismatic, or ellipsoidal types, such as mica and hornblende, so that the rock cleaves readily. Schistosity is a function of compositional differences that developed in layers parallel to the foliation.

Gneissosity.--A type of foliation formed by regional metamorphism resulting in coarse, textural lineations or distinct banding of the constituent minerals into alternating silicious and mafic layers, bands, streaks, or blades.

Banded Rocks

Banded rocks consist of assemblages of parallel, tabular layers of rocks differing in composition, texture, or mineralogy associated with some types of igneous and metamorphic rocks; banding is analogous to bedding in sedimentary rocks. Banding may be inherited from bedding in sediments or from layering in igneous rocks.

Identification

Apply standard geological mapping techniques using a geological compass to determine strike and dip of folded structures (e.g., bedding) and strike and plunge of linear aspects (e.g., fold axes). Use standard mapping symbols for strike and dip, fold axes, and related structures on the geologic evaluation map or sketch of the site (for standard symbols, see AGI Data Sheets, 1989).

Engineering Significance

Folded stratified rocks acquire engineering significance at emergency spillways where dips of inclined beds exceed approximately 2° (3.5 percent). Resistant beds that form the surface (or near surface) of rock spillways can redirect spillway flow in the direction of the dip. Figure 4 illustrates some of the effects of strike and dip in rock spillways.

Corrugations and tight folds with wavelengths of approximately one-half the spillway width or less can also have engineering significance. Where the crest of a tight fold consists of an elevated, prominent ridge of resistant rock, portions of spillway flow can be diverted in the direction of the strike of the fold axis.

The orientation of foliation (gneissosity and schistosity) can have an effect on spillway flow that is analogous to the effect of corrugations and tight folds. Portions of spillway flow can be diverted in the direction of the strike of the foliation. The most favorable orientation of foliation (applies as well to the strike of fold axes of corrugations/tight folds) is within an arc ranging from 15° to 75° in the quadrant pointing away from the dam; the least favorable orientation is within an arc ranging from 105° to 165° in the quadrant pointing toward the dam (figure 5).

The following rules of thumb generally apply in folded rock terrain:

(1) A rock unit dipping away from the dam is more favorable than a rock unit dipping toward the dam. Where the dip is consistent across the valley, consideration should be given to locating the

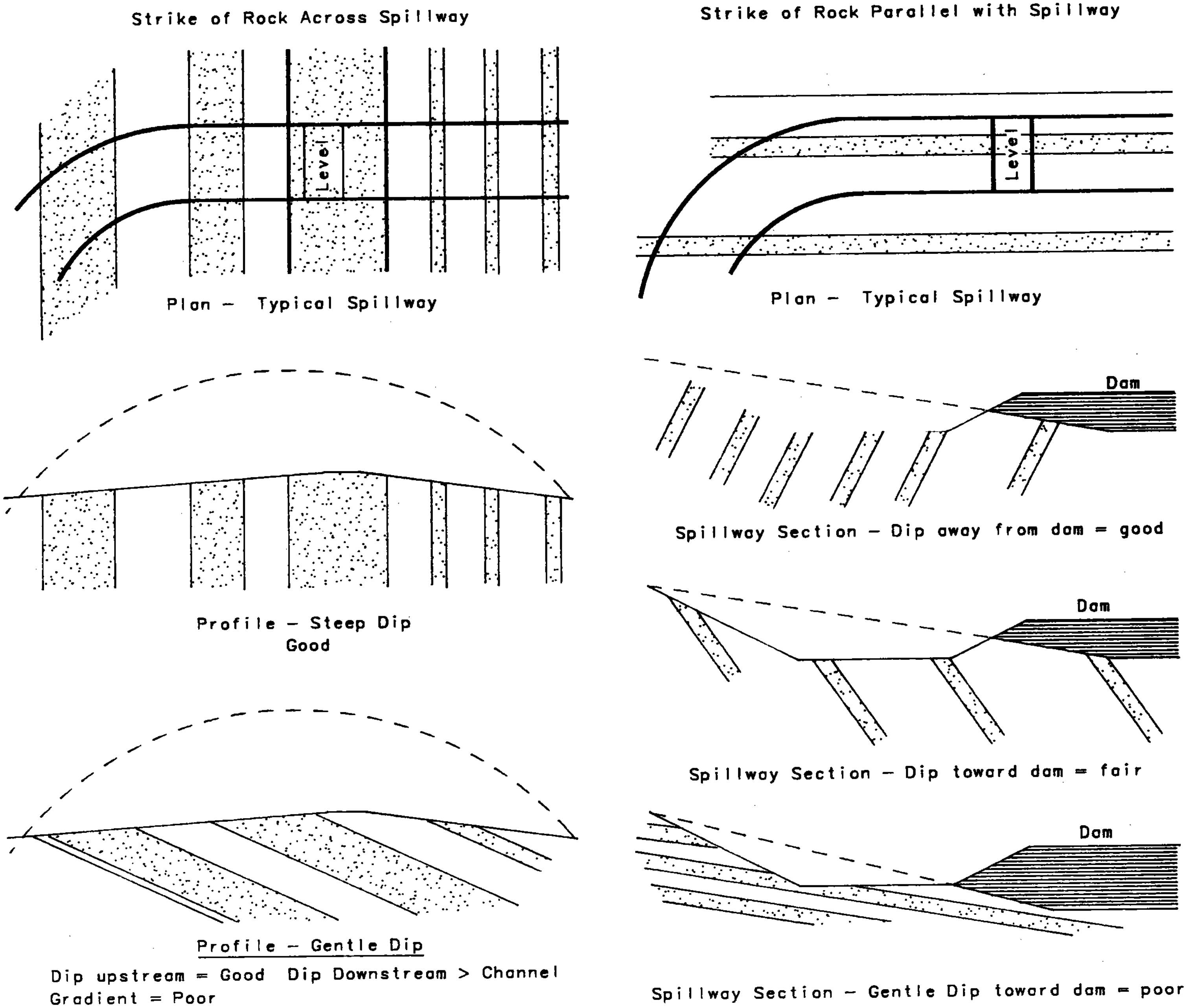
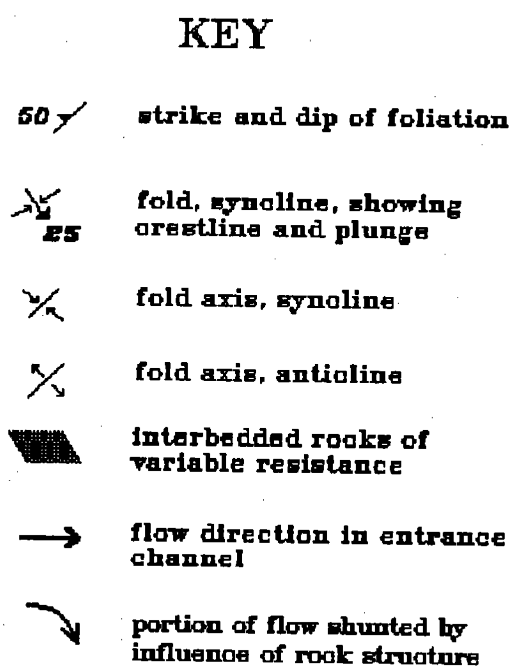
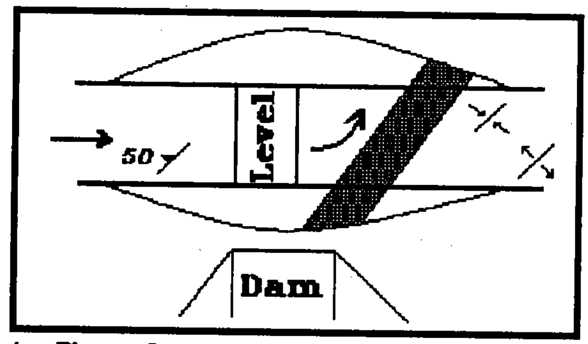


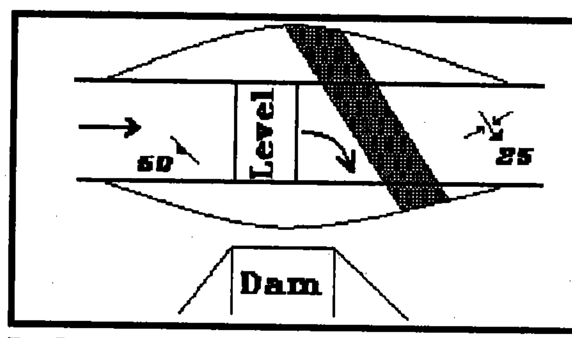
Figure 4 –– Effects of Strike and Dip in Spillway

Figure 5.--Effects of rock structure on spillway flow [Rock structures include trends of fold axes of tight folds or corrugations; trends of foliation (schistosity or gneissosity); and strikes of interbedded rocks of variable resistance.]

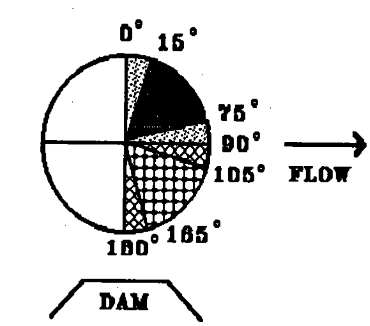




A. Plan – favorable oblique rock structures shunt flow away from dam.



B. Plan – unfavorable oblique rock structures shunt flow toward dam.



Relative favorability of the orientation of rock structure with respect to flow direction and location of dam.

15° - 75°	best
0° - 15°	good
75° - 90°	good
90° - 105°	fair
165° - 180°	fair
105° - 165°	poor

spillway on the abutment that is underlain by rock dipping away from the dam.

(2) A rock unit dipping in the upstream direction is more favorable than in the downstream direction.

(3) A rock unit that dips in the downstream direction, but less than the slope of the exit channel, tends to be more favorable than downstream dips that are greater than or equal to the channel gradient.

DISCONTINUITIES RELATED TO FRACTURE DEFORMATION

Background

A fracture (also called a crack, fissure, rupture, or parting) is a general term, without connotation of genesis, for describing any mechanical break in a rock mass. Fractures are the most common and ubiquitous structural discontinuity in the crust of the Earth; they occur at outcrop scales in all rock types in virtually all structural domains (Davis, 1984). The characteristics of fractures strongly affect the engineering performance of rock for any use.

Rock fractures can occur randomly or systematically and with or without relative displacement across the faces. A joint is a planar or near-planar surface of fracture or parting without visible displacement due to mechanical failure induced by stress in a rock mass. A fault is a fracture with visible relative displacement of opposite faces due to mechanical failure induced by stress.

In this section, the engineering significance of the attributes of fractures is discussed individually. Because these attributes tend to interact and therefore affect the response of the rock mass to hydraulic forces and conditions during spillway flow, the engineering significance of important combinations of the attributes is presented in a final section. These factors control the tendency of the rock mass to deform or fail without necessarily involving breakage of the intact rock material itself.

Random Fractures

A random or nonsystematic fracture is a unique break in the rock with no obvious relationship to any other nearby fracture. A random fracture can originate as a fault or a joint. Random fractures are usually rough and highly irregular and have nonplanar surfaces along which there has been no apparent displacement. Random fractures must be evaluated individually. It is rare, however, to encounter a rock mass with truly random fracturing (Goodman, 1980). Patterns in apparently random fracturing in complex structural domains can often be differentiated by the application of stereographic projection techniques and by the analysis of joint orientation diagrams (see appendix 4, Joint Orientation Diagrams).

Systematic Joints

Systematic joints are fractures that are more or less evenly spaced and oriented in consistent patterns and, thus, are amenable to statistical analysis. Dips of systematic joints are typically high-angle to vertical. They cross other joints; their surfaces are planar or broadly curved. The recognition of joint set patterns may be obvious in the field or may only become apparent after plotting on a stereogram.

Joints are featureless faces that intersect the tops and flanks of outcrops as lines. Partial exposures of joint faces are revealed by erosion, natural spalling, or excavation of the rock mass. A joint set is a group of more or less parallel joints; a joint system is comprised of two or more intersecting joint sets.

Bedding Plane Partings

Bedding plane partings are planar joints or fissures that split the rock along bedding planes. Bedding plane partings reflect changes in depositional conditions that differentiate successive layers in stratified sedimentary rock. The interface between successive layers may or may not be marked by a color change; hence, color change alone should not be used as a criterion for a bedding plane parting unless the color interface clearly corresponds with observable partings in the rock unit.

Sheeting Joints

Sheeting joints (also called stress relief joints) form by expansion or dilation accompanying release of load (pressure) during geologic erosion; they can also be induced by excavation associated with construction activities. Rock is invariably subjected to greater pressure when it is formed than when it is later exposed to the atmosphere. Sheeting joints tend to form roughly parallel to the surface topography and tend to become more widely spaced, flatter, and more regular with depth. They rarely occur more than a few hundred meters deep. In horizontal sedimentary strata, sheeting joints often induce additional dilation on pre-existing bedding plane partings. In massive igneous rocks such as granite, sheeting joints can be spectacularly well-developed by exfoliation; they tend to increase the erodibility of a rock mass and can be used advantageously in rock excavation.

Slaty Cleavage

Slaty cleavage is closely spaced, planar, parallel jointing developed in slates, phyllites, or other tightly folded, homogeneous sedimentary rocks by low-grade metamorphism and deformation. The engineering significance of slaty cleavage is similar to that of fissility (see sections on Joint Spacing and Foliation).

Faults

A fault can occur as a single break or as a fault zone. A fault zone consists of countless subparallel and interconnecting, closely spaced fault surfaces (Davis, 1984) where faulting was particularly intense. The length of faults and shear zones and the amount of relative displacement can range from a few millimeters to hundreds of kilometers.

Documentation

Using table 7 as a guide, record the fracture type.

Table 7.--Fracture type

1. Random Fracture
2. Systematic Joint (high-angle)
3. Bedding Plane Parting
(a) uniformly bedded
(b) cross-bedded
(c) rhythmically bedded
(d) interfingered
(e) graded bedding
(f) current bedding (ripples, etc.)
4. Sheeting Joint
5. Slaty Cleavage, or Fissile Bedding
6. Fault

ATTRIBUTES OF FRACTURES

General

There are many characteristics of fractured rock that influence its erodibility and engineering performance. This technical release focuses on six attributes of fracture phenomena that can be readily assessed in the field. These features include orientation, joint spacing, aperture width of joint face surfaces, type of infilling material, linear persistence, and type of joint ends.

Orientation

Orientation is the establishment of the correct relationship in direction, usually with reference to points of the compass.

Identification.--Use a geological compass to measure the orientation of joints and fractures. If the three-dimensional expression of the joint surface is clear, express its orientation in terms of strike-and-dip. If the outcrop is so smooth and flat that only the trace of the joint is discernible, measure only the trend.

Identify precisely the measurement locations on a geologic evaluation map using standard symbols for strike-and-dip or trend; record ground coordinates and elevation.

For presentation of orientation data for analysis, see appendix 4, Joint Orientation Diagrams.

Engineering significance.--The orientation of joints and fractures within a rock mass with respect to the direction of spillway flow strongly influences the strength anisotropy of the mass. If the direction of spillway flow is oriented perpendicular (+/- 15°) to a persistent systematic joint set, the erosive attack will be acting against the weakest aspect of the rock mass; this relative orientation is the least desirable for the rock mass in resisting erosion. Once hydraulic erosion is initiated, headcutting tends to proceed in a consistent manner as discrete rock particles are eroded from the rock mass, typically in sizes defined by the spacing of the joint sets (figure 6). Obviously, the erodibility of a rock mass increases as joint spacing decreases (see next section on Joint Spacing).

Conversely, for spillways oriented parallel (+/- 15°) with a single persistent systematic joint set, the erosive attack will be acting against the most erosion-resistant aspect of the rock mass; this relative orientation is the most favorable for the rock mass in resisting erosion, provided that there are no persistent systematic joint sets oriented perpendicular to flow (figure 7).

If there are two sets of persistent systematic joints, it is advantageous for the spillway to be oriented such that both sets are oblique to the direction of flow; that is, neither set is within 15° of the direction of flow. This orientation improves discrete particle interlock and provides a more stable position for the center of mass of any given particle (figure 8).

Figure 6.--Joint system with one joint set perpendicular to flow (prone to erosion)

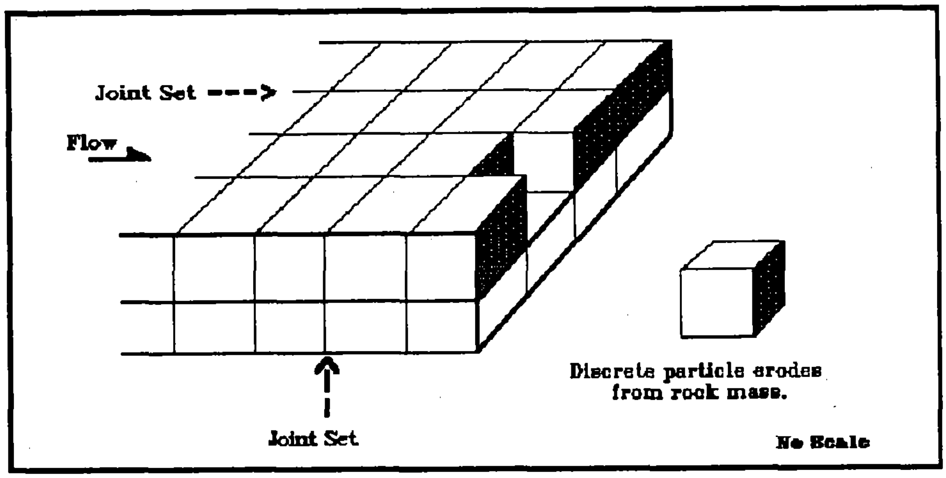


Figure 7.--One joint set parallel to flow (resists erosion)

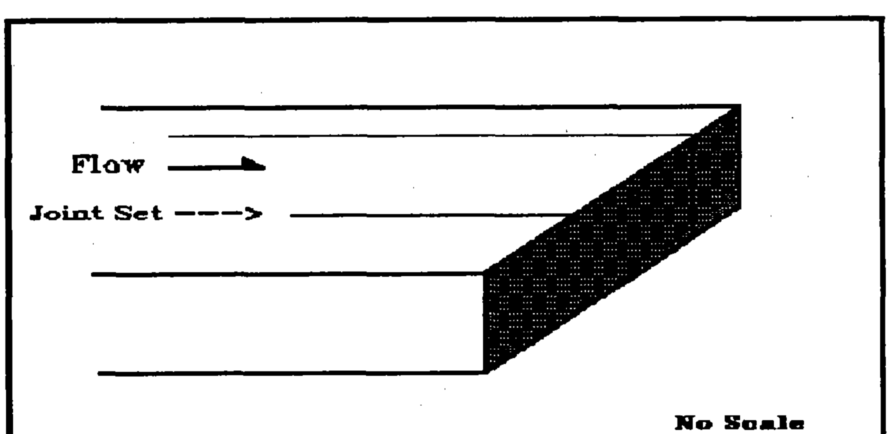
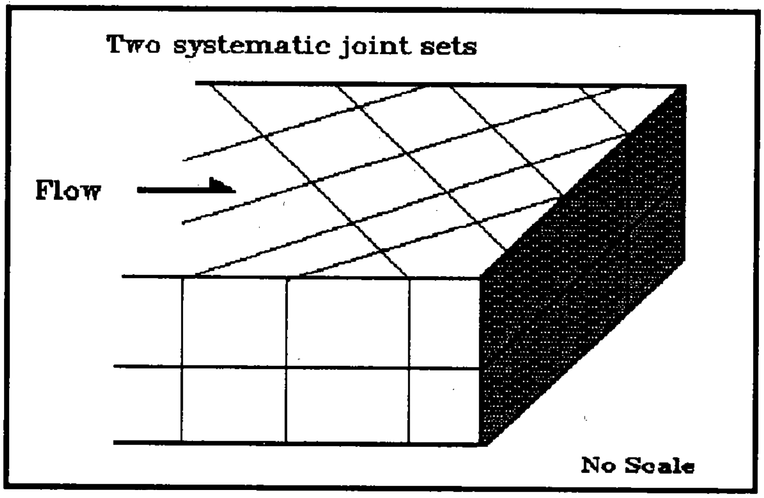


Figure 8.--Joint system with both sets oblique to flow (resists erosion).



Joint Spacing

Joint spacing is the average spacing of joints within a joint set expressed in meters (or millimeters). The spacing and orientation of joints and bedding plane partings determine the size and shape of discrete rock particles.

Identification.--Use the fixed line survey method (appendix 2) to determine joint spacing. For systematic joints, place a 10 m tape perpendicular to the trend of the each joint set, count the number of joints that intersect the survey line, and divide the number counted by 10 to determine the average joint spacing. For random fractures, measure in three mutually perpendicular directions, if possible. If the vertical component is not available because of outcrop constraints, use data from drilling logs or rock core samples, if available, to assist in estimating the spacing.

Although a different set of terms for bedding plane partings has been used for years in classic field geology (Ingram, 1954), the recommendation is to use one common set of terms to describe both bedding plane partings and high angle joints. Descriptive terms should be consistent with the usage in table 8 (adapted from Bieniawski, 1988; Goodman, 1976; GSL, 1977; ISRM, 1981, and Watkins, 1970).

Record the spacing of joints in each set and use table 8 as a guide for defining the spacing category.

Determine the mean diameter (d_{50}) of discrete rock particles by taking the cube root of the product of the average joint spacing of the three most prominent intersecting joint sets. For example, a rock mass with two intersecting vertical joint sets, one with an average spacing of 1.00 m and the other 2.00 m, and with bedding plane partings 0.10 m, will produce discrete rock particles with a mean diameter of 0.6 m. A mean diameter greater than or equal to 0.20 m is used in the definition of rock in excavated earth spillways. For values less than 0.20 m, the mode of erosion of earth materials begins to emulate conditions for moveable spillway channel boundaries.

Table 8.--Spacing categories for joint sets

SPACING CATEGORIES		SPACING
Bedding Plane Partings	High Angle Joints	(Meters)
Massive/unstratified	Extremely wide	> 6.000
Very thick-bedded	Very wide	2.000 - 6.000
Thick-bedded	Wide	0.600 - 2.000
Medium-bedded	Mod. wide	0.200 - 0.600
Thin-bedded	Mod. close	0.060 - 0.200
Very thin-bedded	Close	0.020 - 0.600
Laminated	Very close	0.006 - 0.020
Thinly laminated	Shattered	0.002 - 0.006
Fissile	Fissured	< 0.002

Engineering significance.--The size and shape of discrete rock particles are initially determined by the joint spacing of intersecting joint sets and bedding plane partings. The size of discrete rock particles strongly affects the erodibility of a rock mass. As the spacing of bedding plane partings and joints decreases, the erodibility and excavatability of a rock mass tend to increase.

Fissility is a primary foliation feature that is common in fine-grained sedimentary rocks, particularly shales. Most shales are fissile or laminated; fissility distinguishes shale from claystone or siltstone. In many shales the most prominent fissility is parallel to the bedding, but in others it is not. Fissility is akin to slaty cleavage; it can occur in unmetamorphosed shales cutting the stratification at steep angles, and can easily be mistaken for bedding (Dunbar and Rogers, 1966). Fissility is responsible for the unravelling of shales under hydraulic attack. Fissility is a qualifier of material strength as it predisposes rock to mechanical weathering processes (wetting and drying, freeze-thaw, etc.) that can cause the rock to slake and disintegrate between flow events.

Aperture Width of Joint Face Surfaces

Aperture (syn.: planar separation) refers to the opening between opposing faces of a joint, fracture, or fault.

Identification.--In most instances, the width of an aperture is not constant along the trace of any given fracture or joint; therefore, a range category is recommended in table 9. Determine the aperture width category of each selected joint by measuring the aperture width at a sufficient number of places along the trace of the joint. If the width of an aperture of a particular joint varies through more than one range, state the length of the trace for which the aperture width category applies. For example, a 20-meter long joint has a narrow aperture width (6 - 20 mm) for 13 m and widens to moderately narrow (20 - 60 mm) for 7 m. Clarify the variability by describing the joint in separately labeled segments on the Discontinuity Data Sheets, and show the location of the joint on the geologic evaluation map.

Table 9.--Aperture width categories

Aperture Width Category	Width Range (mm)
Wide	> 200
Moderately wide	60 - 200
Moderately narrow	20 - 60
Narrow	6 - 20
Very narrow	2 - 6
Extremely narrow (hairline)	> 0 - 2

Engineering significance.--The aperture width of a joint affects the movement of water into the opening. The wider the aperture, the greater the potential for movement of the particle by uplift forces and pore pressure.

Infilling

Infilling is the material occupying the aperture between joint faces; it is often referred to as gouge, breccia, or mylonite (for faults). The materials deposited in an opening can include air-borne or washed materials, such as silt, clay, and other organic and mineral matter; or may include partially or completely remineralized vein deposits.

Identification.--Soil materials in open fractures should be described according to standard soil logging terminology and classified by ASTM D-2488 in the field or D-2487 in the lab (Unified Soil Classification System). Chemically precipitated or remineralized material in fractures should be identified by composition (quartz, carbonate, gypsum, etc.). The thickness of the infilling is usually the same as aperture width.

For each evaluated joint, record the general nature of the infilling according to the scheme in table 10. Report in the notes any range in variability.

Table 10.--Nature of infilling

1. Clean, open, unaltered walls; surface staining only.
2. Non-plastic silt (Plasticity Index < 10) sand, gravel, with or without crushed rock.
3. Inactive clay or clay matrix, with or without crushed rock.
4. Swelling clay or clay matrix, with or without crushed rock.
5. Chlorite; talc; mica; serpentine; other sheet silicates; graphite; gypsum.

Record the classification of the material according to the Unified Soil Classification System, ASTM D-2488.

The strength of the infilling can be estimated using table 5, Correlation of Earth Material Hardness Categories with Laboratory Uniaxial Compressive Strength, or measured with a pocket penetrometer or pocket vane tester for soils.

Engineering significance.--The resistance to sliding of adjacent joint blocks, which affects excavatability, slope stability, and hydraulic erosion, can be either increased or decreased depending on the (1) aperture width; (2) continuity, texture, plasticity, consistency, permeability, and unconfined compressive strength of the infilling; and (3) the character of the joint walls (Kirsten, 1988). Coatings or infillings of chlorite, talc, graphite, or other low strength materials need to be identified because of their adverse effects on the erodibility of the rock mass, especially when wet. Infillings that are dispersive or micaceous can squeeze or erode under fluid flow, thus contributing to increased erodibility and instability of the rock mass (BuRec, 1989). Montmorillonitic clays can swell or cause swelling pressures. Fluid flow can readily remove cohesionless silts and sands allowing for the entry and passage of moving water which can cause uplift and sliding pressures on the discrete rock particles.

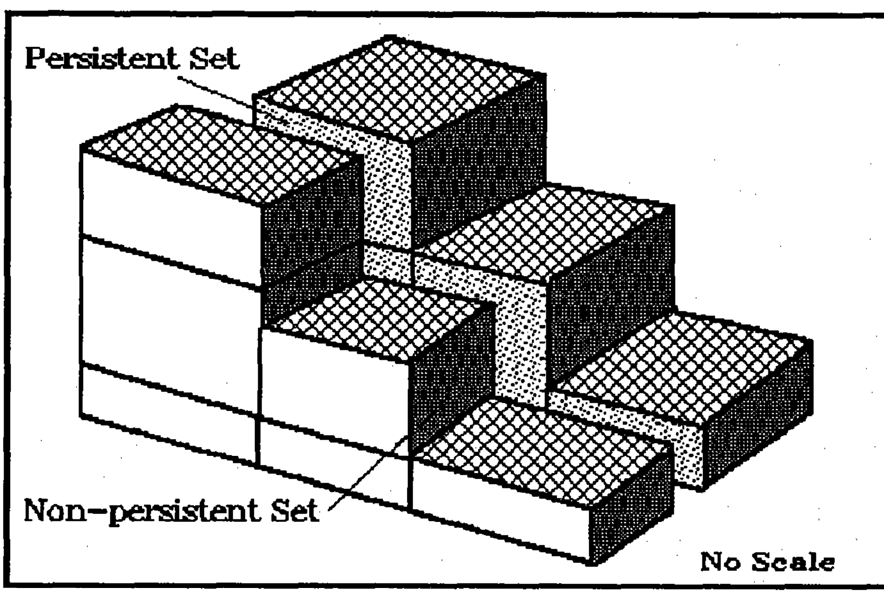
Linear Persistence

Linear persistence is the extent to which an individual fracture can be traced within a plane.

Persistence is one of the most important factors in rock performance evaluation. However, it is usually difficult to measure adequately because joints often extend beyond the outcrop area. Persistence can be quantified by measuring the discontinuity trace lengths on the surface of exposures (ISRM, 1981).

The joints of some sets will often be more continuous than those of other sets. Minor sets tend to terminate against primary sets or may terminate in solid rock (figure 9).

Figure 9.--Persistent and non-persistent joint sets



Identification.--Specify the dimensions of the exposed area of the outcrop on which measurements will be made since this will affect the number of observations and relative lengths.

Measure, in meters, the lengths of all selected joint traces in the direction of strike and in the direction of dip, if discernable. Note whether it is a strike, dip, or apparent trace.

Using table 11 as a guide, record the persistence category of each identified joint.

Table 11.--Joint trace persistence categories

Joint Trace Persistence Category	Trace Length Range (Meters)
Very low persistence	< 1
Low persistence	1 - 3
Medium persistence	3 - 10
High persistence	10 - 20
Very high persistence	> 20

Engineering significance.--Linear persistence strongly affects the hydraulic erodibility of a rock mass. A rock mass interrupted by highly persistent joints is potentially more erodible than a rock mass with less persistent joints. The higher the persistence category of systematic joint sets in a rock mass upstream of the crest of a slope or overfall, the greater the tendency for the development of tension cracks during flow. The persistence factor determines the height and width of a step which would occur between adjacent joints for a tension (failure) surface to develop and for the process to repeat itself.

Joint Ends

Joint ends refer to the nature of the terminations of a joint. Joints can terminate in solid rock or they can terminate against another joint (like the letter "T"). Intersecting or through-going joints (like the letter "X"), are not considered to terminate at the intersection.

Identification.--Record the type of joint termination for both ends of each joint according to the scheme in table 12. Figure 10 provides illustrated examples. Note that all length measurements in Type B are considered to be minimum values since the ends are not observable.

Figure 10.--Types of joint ends in a rock outcrop.

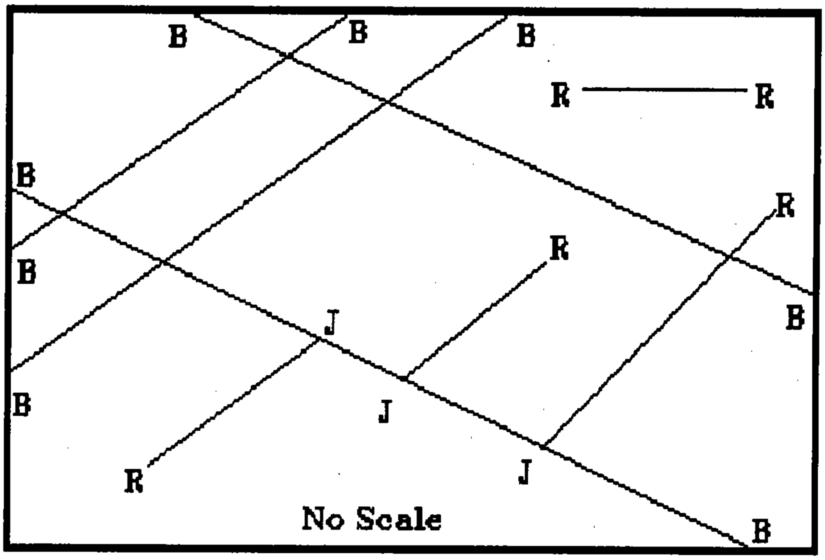


Table 12.--Types of joint ends.

Type R	= Joint end terminates in solid rock
Type J	= Joint end terminates against another joint
Type B	= Joint end extends beyond outcrop area

Engineering significance.--The type of joint end strongly influences the erodibility of a rock mass. Joints that terminate in solid rock have the least potential for forming a discrete rock particle. Joints that terminate against other joints greatly increase the erodibility of the rock mass, particularly, if there is a persistent systematic joint set oriented perpendicular to flow (+/- 15°).

General Engineering Significance of Attributes of Fractures

Hydraulic erodibility of rock is a function of complex interactions between rock material/rock mass properties and the hydraulic conditions of flow. Fracture-type discontinuities are generally the most influential to rock mass erodibility. Although several important attributes of fractures have been identified and their engineering significance discussed individually in this technical release, it is clear that in order to predict engineering performance of excavated rock spillways, these attributes must be considered in an interdependent and interactive context. Table 13 summarizes the range in influence of attributes of fractures/joints on the erodibility of a rock mass.

Table 13.- Summary of the influences of fracture attributes on erodibility of a rock mass

Joint/Fracture Attribute	Most Favorable	<——>	Least Favorable
Orientation	Parallel to flow or away from dam	<——>	Perpendicular to flow or toward dam
Joint spacing	Extremely wide	<——>	Fissured
Bedding plane parting	Massive or unstratified	<——>	Fissile
Aperture width	Extremely narrow	<——>	Wide
Infilling	Filled Plastic Inactive clay	<——> <——> <——>	Open Nonplastic Swelling clay or sheet silicates, talc, graphite, or gypsum
Joint face	Unaltered	<——>	Altered
Persistence	Very low	<——>	Very high
Joint end type	Terminates in rock	<——>	Terminates against another joint

Systematic joints and random fractures within a rock mass reduce its integrity and stability, and increase its excavatability and erodibility. Additionally, by increasing the surface area on the rock mass, jointing increases the susceptibility to physical and chemical weathering which, in turn, will further weaken the rock mass over time.

In addition to weakening a rock mass by fracture, faults can juxtapose rock masses of widely differing engineering characteristics, which may lead to the formation of knickpoints and differential erosion of earth materials during spillway flow. Additionally, the trace of a fault can be exploited by hydraulic erosion, thereby directing portions of the flow in the direction of the trace; an orientation toward the dam or retaining dike is, therefore, unfavorable.

How the spillway channel is laid out with respect to pertinent rock features can greatly affect its performance. In many cases, even relatively small changes in layout can either take advantage of favorable rock characteristics or avoid adverse features, resulting in significant improvement in spillway performance.

CHAPTER 6. PROPERTIES RELATED TO BOTH ROCK MATERIAL AND ROCK MASS

INTRODUCTION

Physical properties that are related to both the rock material and the rock mass include seismic velocity, weathering, and secondary cavities. Each of these characteristics can affect the hydraulic erodibility and excavation characteristics of rock.

SEISMIC VELOCITY

Definition

Seismic velocity (also called sonic velocity) is the velocity of propagation of pressure waves through a rock mass.

Background

Seismic velocity is a function of many rock material properties, including density, porosity, mineral composition, and the degree of cementation and consolidation; and rock mass properties, including degree of fracturing and degree of weathering. Different seismic velocities are also obtained for wet and dry joint apertures in rock masses which are otherwise identical.

Identification

The seismic velocity of an earth material is determined by a seismic survey using standard refraction techniques conducted by personnel with appropriate training and experience.

Engineering Significance

Generally, the lower the seismic velocity of a rock mass, the greater the erodibility and excavatability of the rock mass. Although there are little data on the relationship between seismic velocity and hydraulic erosion resistance of earth materials, most earth materials with seismic velocities less than 1000 m/sec are prone to particle-by-particle erosion (Caterpillar Tractor Company, 1983; Kirsten, 1982); an obvious exception is highly plastic, nondispersive clay. The "Little Bear Residuum" in the Lower Mississippi River Valley is an example of an extremely erosion-resistant residual soil associated with limestone parent material (Mellen, 1937; Moore, 1978).

A relationship may exist between rippability and hydraulic erodibility of rock, although no definitive study has been published to date (Moore, 1988; Kirsten, 1982 and 1988; Cameron, et. al., 1988a). Caterpillar Tractor Company (1983) correlates the seismic velocities of some broad categories of earth materials with ripping performance of tractors.

Seismic refraction surveys are routinely conducted during preliminary dam site investigations to provide a rapid assessment of depth to rock, configuration of the rock surface, and an indication of the relative integrity of foundation materials. The results of a seismic survey must be considered provisional until supplemented with "ground-truth" provided by conventional drilling and excavation techniques in subsequent detailed investigations.

WEATHERING

Definition

Weathering is the physical disintegration or chemical decomposition of earth materials resulting in changes in the color, texture, composition, density, or form, with little or no transport of the loosened or altered material. In this technical release, the scope of weathering is limited to the condition of the joint face rock material.

Background

The effects of weathering tend to diminish with depth and are best assessed on a macroscopic scale in the field.

The rate and type of rock weathering depend upon climate, topography, vegetation, time, and the physical and chemical composition of the rock.

Physical weathering is the disintegration of rock into essentially unaltered pieces by the following processes: (1) differential expansion by pressure release when rock is exposed at the surface or confining forces are otherwise reduced; (2) growth of crystals, such as ice or salt in cracks and pores; (3) differential expansion and contraction during cyclic heating and cooling; and (4) the prying action of roots.

Chemical weathering is the decomposition of the chemical structure of the mineral grains that make up a rock. All chemical weathering reactions use water as either a reactant or the carrier of reactant products. The chief chemical weathering processes are hydration, hydrolysis, oxidation, carbonation, and solution.

Identification

Use descriptors in table 14 to classify the weathering condition of the joint face rock material of identified joints.

Table 14.--Descriptors for weathering condition of joint face rock material (after ISRM, 1978)

Descriptor	Weathering Condition of Joint Face Rock Material
Fresh	No sign of weathering of joint face rock material.
Discolored	Joint face rock material is iron-stained or discolored, but otherwise unweathered.
Disintegrated	Joint face rock material is physically disintegrated to a soil condition with original fabric still intact. Material is friable and mineral grains are not decomposed.
Decomposed	Joint face rock material is chemically altered to a soil condition with original fabric still intact; some or all of mineral grains are decomposed.

Engineering Significance

Physical weathering results in the widening of existing discontinuities, the creation of new discontinuities by rock fracture, the opening of grain boundaries, and the fracture or cleavage of individual mineral grains.

Chemical weathering results in staining of rock surfaces in its early stages. Long term chemical weathering results in the formation of clay minerals and chemical changes in the original minerals; in soluble rocks, it results in the widening of joints and the development of caves and other karst phenomena.

Weathering of rock material lowers the integrity of the rock and reduces its resistance to erosion and excavation. In some parts of the country where some rock materials have consistently proven to weather rapidly (e.g., some shales in the Appalachian States or the Plains States), soil liners have been applied to the rock surface to inhibit weathering processes. Often, the depth of weathering amounts to only a few centimeters over a period of decades, so the effort may not be justified except for aesthetic reasons.

SECONDARY CAVITIES

Definition

Secondary cavities are open holes and voids, such as pits, vugs, and vesicles, that form as a result of chemical or mechanical processes acting on the rock mass after its formation.

Background

These types of secondary cavities are exclusive of fractures, jointing, and other open, planar, secondary features which are addressed in chapter 5, ROCK MASS PROPERTIES: STRUCTURAL DISCONTINUITIES.

Identification

Identify the type of secondary cavities, if present, using the descriptors in table 15 as a guide.

Table 15.--Descriptors for secondary cavities

1. Pitted. Small openings, 1 to 10 mm in diameter.
2. Vuggy. Small openings ranging from 11 to 100 mm in diameter (usually lined with crystals).
3. Cavitied. Openings larger than 100 mm. Give sizes and shapes.
4. Honeycombed. If numerous enough that only thin walls separate individual pits or vugs, this term further clarifies the above terms to indicate cell-like form.
5. Vesicular. Small openings in volcanic rocks of variable shape formed by entrapped gas bubbles during solidification.

Engineering Significance

These types of features reduce the integrity of the rock mass by increasing porosity and by decreasing strength and unit weight. By increasing the surface area of the rock mass, secondary cavities increase its susceptibility to physical and chemical weathering, which, in time, will further weaken the rock mass.

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APPENDIX 1

GLOSSARY

Bedrock. A general term for in-place (in-situ), usually solid rock that is exposed at the surface of the Earth or overlain by unconsolidated material. Colloquial syn.: ledge. See **Rock Mass.**

Bedding Plane. A bedding plane is a planar or near planar interface that reflects a change in depositional conditions indicated by a parting, color difference, or both, and defines successive layers of stratified rock.

Cleavage. The property or tendency of a rock to split along secondary, aligned fractures or closely spaced, planar structures produced by deformation or metamorphism.

Clastic. Pertaining to a rock or sediment composed principally of broken fragments that are derived from preexisting rocks or minerals and that have been transported some distance from their places of origin. See **Pyroclastic.**

Corrugations. Small-scale, tight folds; wrinkles; or furrows.

Density. The mass of a unit volume of substance at a specified temperature, expressed in SI units of kilograms per cubic meter, but often is reported in grams per cubic centimeter. Syn.: unit weight, weight per unit volume.

Discontinuity. Any distinct break or interruption in the integrity of a rock mass. See **Stratigraphic Discontinuity; Structural Discontinuity.**

Discrete Rock Particle. are An intact, sound fragment of rock material whose shape and size ~~is~~ defined by the discontinuities that form its margins. The mean diameter of a rock particle is defined as the cube root of the product of its three dimensions (length, width, and thickness). Syn.: rock block, intact block.

Durability. The resistance of discrete rock particles to breaking down over time due to weathering processes, hard wear, and abrasion. Syn.: weatherability.

Earth Material. The entire spectrum of soil and rock materials. See table 5 for the ranges in strength and hardness of earth materials.

Earth Spillway. An open channel spillway in earth materials without vegetation (SCS, TR-60).

Fault. A fracture or fracture zone along which there has been relative displacement of opposite faces, due to mechanical failure by stress in a rock mass.

Fissility. The tendency of a rock to split or part into thin layers or plates. Bedding fissility is a primary feature inherited from the time of deposition; it is the result of compaction with concomitant recrystallization, and to some degree, is due to the parallel arrangement of platey or elongated, fine-grained mineral particles (Pettijohn, 1957).

Fold Axis. The intersection (which is a line) of the axial surface of a fold with any bed. The axial surface is the plane or surface that divides the fold as symmetrically as possible.

Fracture. A general term for any physical break in a rock mass without regard to the nature of the origin of the break. Syn.: crack, fissure, rupture, parting.

Freeboard Hydrograph. The hydrograph used to establish the minimum settled elevation of the top of dam; also used to evaluate the structural integrity of the spillway system (SCS, TR-60, Oct 1985).

Geologic Evaluation Map (GEM). A plan-view diagram or drawing, representing a given area, depicting the orientation and location of selected geologic features using appropriate signs and symbols, at a chosen scale and projection. See **Sketch Map.**

Groundmass. [ign] The glassy or fine-grained crystalline material between the larger crystals of a porphyritic igneous rock.

Intact Rock. Rock containing no discontinuities. Syn.: rock material.

Joint. A planar or near-planar surface of fracture or parting without visible displacement, due to induced mechanical failure by stress in a rock mass.

Joint Set. A group of more or less parallel joints.

Joint System. Two or more joint sets that intersect.

Knickpoint. Any interruption or break of slope; especially a point of abrupt change or inflection in the longitudinal profile of a stream or of its valley, resulting from rejuvenation or the outcropping of a resistant bed.

Lithosome. A lithosome is a body of sedimentary rock of uniform character which has intertonguing relationships with adjacent masses of different lithology (Krumbein and Sloss, 1963, p. 301). There is no implication of formal rock-stratigraphic nomenclature.

Master Joint. A persistent joint plane of greater-than-average extent. Syn.: main joint, major joint, regional joint.

Pyroclastic. Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent; it is not synonymous with the adjective "volcanic". See **Clastics.**

Rock Mass. Rock as it occurs in situ, including its system of discontinuities, and weathering profile (SCS, TR-71, Feb 1987; also see ASTM, 1986). Syn.: bedrock, rock outcrop. Colloquial: ledge.

Rock Mass Properties. Measurable or otherwise describable lithologic properties, characteristics, or features of the rock mass that must be evaluated on a macroscopic scale in the field. Normally, rock mass properties, such as joints and faults, are too large to be observed directly in their entirety and are difficult to impossible to sample for laboratory analysis (SCS, TR-71, Feb 1987).

Rock Material. An intact, natural body or aggregate of solid mineral matter that is free of discontinuities, such as joints. Syn: intact rock, intact rock material.

Rock Material Properties. Measurable or otherwise describable properties of intact rock material that can be evaluated in hand specimen (and, in many instances, in outcrop) and thus can be subject to meaningful inquiry in the laboratory. The properties of rock material depend on the physical properties of the constituent minerals and their type of bonding to one another. The properties can be determined from the examination of hand specimens, core sections, drillcuttings, outcroppings, and disturbed samples.

Rock Unit. An identifiable body of rock that is consistent in mineral, structural, and hydraulic characteristics. A rock unit can be considered essentially homogeneous for engineering performance analysis and for descriptive and mapping purposes. A rock unit can be delineated by measurable or otherwise describable physical properties or features (SCS, TR-71, Feb 1987). The term is similar to **lithosome** in that the body of rock has consistent, mappable characteristics, but differs in that the body need not have been formed under uniform physico-chemical conditions.

Sheeting Joint. A joint that forms by expansion (also called dilation, scaling, and exfoliation) accompanying release of load (pressure) during geologic erosion. Syn.: pressure release joint, stress relief joint, sheeting.

Sketch Map. A map drawn free-hand from observation or uncontrolled surveys showing only approximate space, scale, and orientation relationships of the main features of an area.

Slaty Cleavage. Closely spaced, planar, parallel jointing of fine-grained, platy minerals developed in slates and phyllites by low-grade metamorphism; or in tightly folded, homogeneous sedimentary rocks by deformation. Slaty cleavage is perpendicular to the direction of greatest shortening of the rocks in which it is formed.

Standard Practice. A definitive procedure for performing one or more specific operations or functions that does not produce a test result.

Stratigraphic Discontinuities. Features that originate contemporaneously with the formation of a rock mass. Syn.: primary discontinuities, first order discontinuities, syngenetic discontinuities.

Structural Discontinuities. Features that develop after the initial formation of the rock as a result of external processes acting on the rock mass. Syn.: secondary discontinuities, second order discontinuities, epigenetic discontinuities.

Structural Domain. A geologic locality having rock masses with similar major lithologic and structural features. Syn.: structural region.

Tight Folds. Fold with an inter-limb angle between 0° and 30°.

Trace. The intersection of a geological surface with another surface, e.g., the trace of a fault on the ground. The trace is a line. Syn.: trend, strike.

Unconformity. The surface separating two rock units that are not in stratigraphic sequence resulting from a change in regimen which caused deposition to cease for a substantial period of time; an unconformity usually implies geologic uplift and erosion.

Vein. An epigenetic mineral filling or deposit in the aperture of a fracture in a rock mass, in tabular or sheet-like form. Quartz and calcite are the most common vein minerals.

APPENDIX 2

THE FIXED LINE SURVEY

Definition

A fixed line survey is an inventory of all structural discontinuities that intersect a linear traverse of specified length and orientation.

Application

In structural domains where joint set patterns are obvious, the fixed line survey can be used to make rapid determinations of joint set spacings, which, in turn, are used to determine mean diameter and shape of discrete rock particles.

In complex structural domains where joints and fracture patterns are difficult to discern, the fixed line survey can be applied to differentiate subtle joint patterns and to inventory a representative sample of the joints for assessment of joint attributes.

If the survey line is parallel with the trend of a dominant joint set, the method is subject to potential undersampling and data bias.

Procedure

The rock outcrop in the area of interest must be well exposed, clean, and accessible for measurement and study. Cleaning can be accomplished by whatever means is necessary, including power equipment, hand tools, or pressurized air or water.

To determine the average spacing of a persistent systematic, high-angle joint set, orient a measuring tape perpendicular to the trend of the joint set. The length of the survey line will depend on the spacing of the joints and the amount of outcrop available for measurement. As a rule of thumb, 10 meters or 10 joints, whichever is greater, is the recommended length of the survey line. Widely spaced joints will obviously require a longer line to obtain a meaningful average. In some instances, outcrop limitations will necessitate shorter lines. Determine the spacing for each persistent joint set. To measure the number of bedding plane partings or sheeting joints on steep outcrops, place a weighted tape or telescoping range pole against the face. In situations where the vertical component is not exposed, estimate the spacings using drilling logs or drill core samples of test holes in the spillway near the survey line.

For complex structural domains with abundant unique fractures, establish three mutually perpendicular axes for survey lines--one axis parallel with the spillway flow direction and another perpendicular to the flow. The third axis, the vertical component, is described in the previous paragraph. The discrete rock particle mean diameter is determined by taking the cube root of the product of the average joint set spacings in the three surveyed directions.

To improve the determination of the average joint set spacing in a given dimension, survey more than one line. For example, use three parallel survey lines 5 meters apart and average the results. The number of lines needed is a function of the size and geologic complexity of the site.

Documentation

Show the location of each line on a geologic evaluation map and record its orientation, elevation, and ground coordinates or stationing on the Discontinuity Data Sheets.

The attributes of all structural discontinuities which intersect the fixed lines are then measured according to procedures described in this technical release and recorded on the Discontinuity Data Sheets.

APPENDIX 3

THE FIXED AREA SURVEY

Definition

A fixed area survey is comprised of an inventory of all structural discontinuities within a sampling station of specified area and shape.

Application

The fixed area survey is a detailed assessment of structural discontinuities at a project site.

The specified area may include: the entire emergency spillway; selected reaches between the control section and the outlet of the exit channel; or offsite areas that are considered germane to the study objectives. The shape of the survey area is usually square or rectangular; however, in some instances, a circular or rhomboidal shape may be useful.

Procedure

The rock outcrop in the area of interest must be well exposed, clean, and accessible for measurement and study. Cleaning can be accomplished by whatever means is necessary, including power equipment, hand tools, or pressurized air or water.

For mapping large areas or areas with a high density of fractures, subdivide the study area into manageable sub-areas. For square or rectangular areas, the sub-areas can be quarters, ninths, sixteenths, twenty-fifths, etc. of the total area. These sub-areas must be labelled appropriately.

To avoid measuring the same joint or feature twice, it is helpful to trace out with chalk the full length of each joint after it is measured.

Documentation

The attributes of all structural discontinuities within the survey area are evaluated according to procedures described in this technical release and recorded on the Discontinuity Data Sheets. Show the location of each feature on the geologic evaluation map, sketch, or on the corresponding sub-area map.

APPENDIX 4

JOINT ORIENTATION DIAGRAMS

Introduction

Joint orientation diagrams are useful statistical tools in the analysis of orientation data of joints, faults, and unique fractures. Preferred orientations can often be ascertained from data collected in complex structural domains. Structural orientation data can be summarized in pole diagrams, pole-density diagrams, rose diagrams, and strike histograms.

The analysis of joint data consists of standard and well known procedures in geological mapping. The information presented below is meant to be an overview of joint orientation diagrams. For further information, refer to SCS TR-41 (1969); Hoek and Bray, Ch. 3 (1981); or standard texts such as Billings, Ch. 7 (1954), Davis, Ch. 3 (1984), or Ragan (1984).

Three-dimensional Plots

Pole diagrams and contoured pole-density diagrams.--Pole diagrams are spherical projections (stereographic displays) of three-dimensional, strike-and-dip data. There are two types of stereographic diagrams (figure 11):

> The Wulff net--an equal-angle projection in which the angular relationships between features are accurately represented.
>
> The Schmidt net (Lambert projection)--an equal-area projection in which the spatial distribution of data is accurately represented.

The Schmidt net is the preferred stereographic projection for joint analysis; the Wulff net is not recommended because it has a built-in bias that invalidates the statistical distribution of plotted points (Hoek and Bray, 1981).

All joint pole data are plotted onto a Schmidt net to distinguish joint set patterns. Contouring the values of the density of the poles (the concentration or number of points per unit area) on the resulting scatter diagram provides a measure of the degree of preferred orientation of structures in complex rock masses.

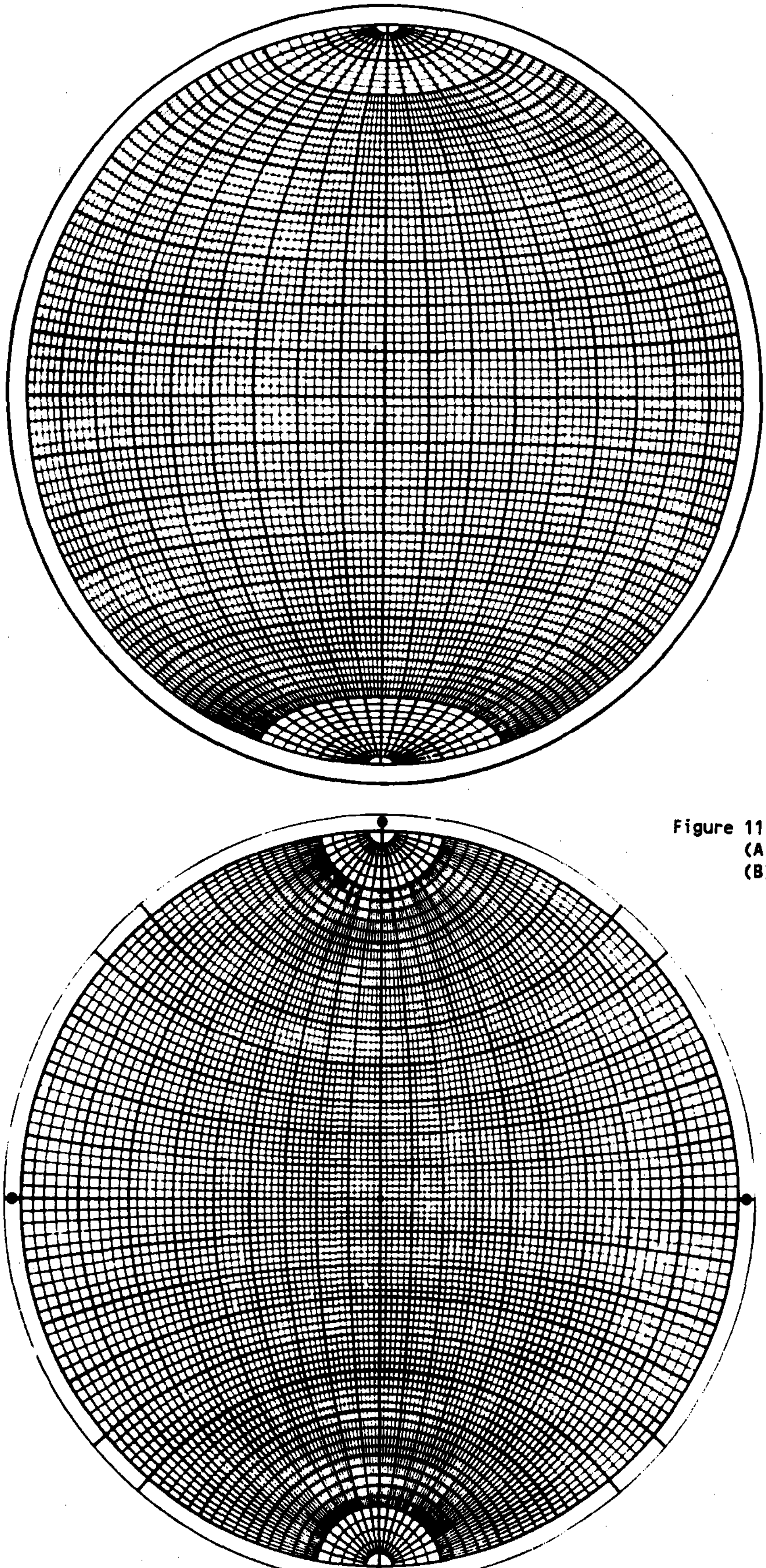


Figure 11.--Stereographic projections:
(A) Schmidt net (equal-area),
(B) Wulff net (equal-angle).

(After, STRUCTURAL GEOLOGY OF ROCKS AND REGIONS, by G. H. Davis, 1984, Wiley)

Two-dimensional Plots

Where three-dimensional control on the attitude of the joints cannot be attained, either due to the nature of the surfaces of the outcrop or due to the collection of joint orientations from aerial photos, the orientation data can be plotted on two dimensional plots, such as rose diagrams or strike histograms. In preparing rose diagrams and strike histograms, the trend and/or strike data are first organized into intervals of 5° or 10°, encompassing the orientation range from west through north to east. The number (or percentage) of readings within each interval is summed. Data can then be plotted as either a rose diagram or a strike histogram (Davis, 1984).

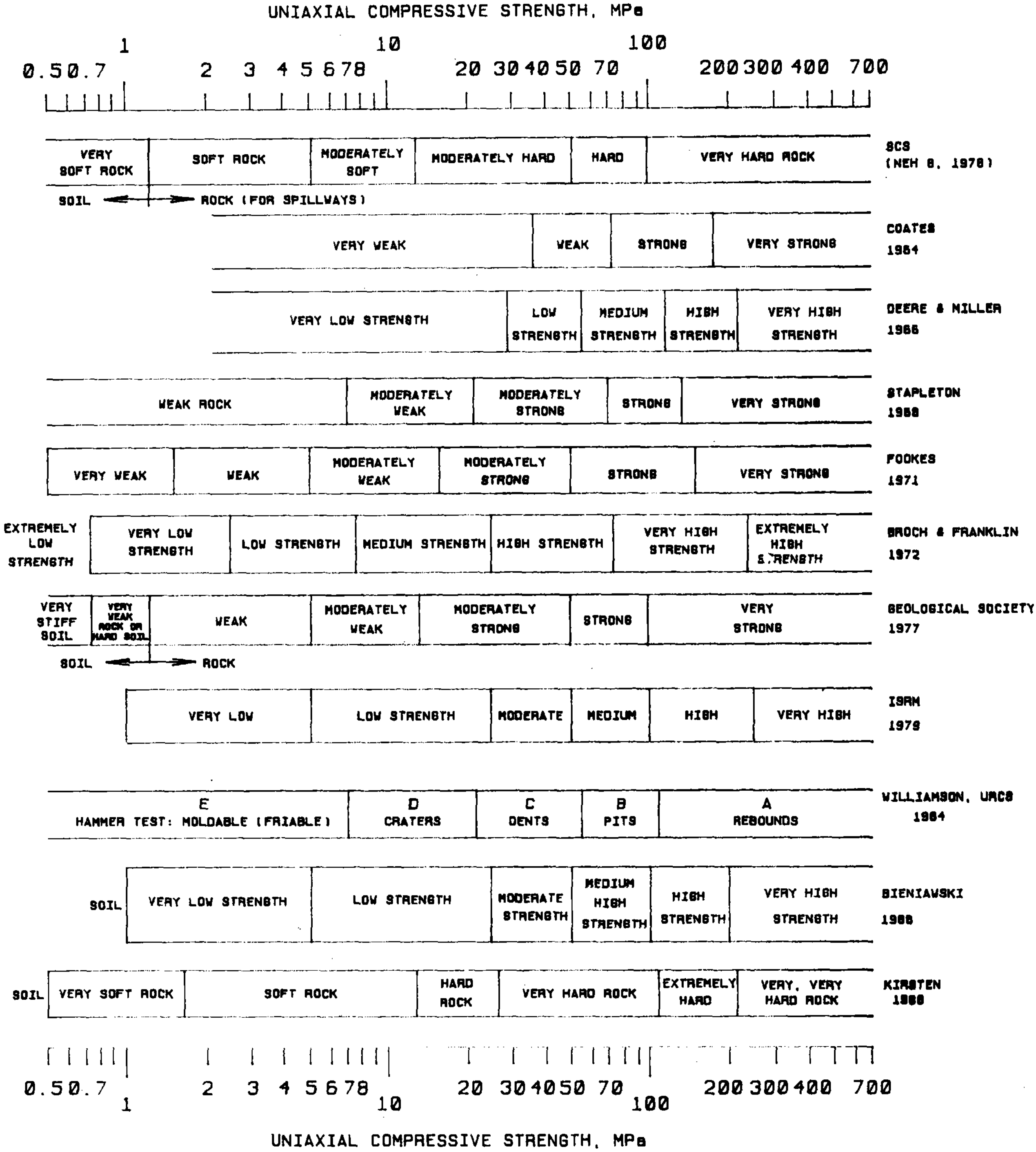
Rose diagrams.--The number (or percentage) of joints that occur in each 5° (or 10°) interval is plotted in a family of concentric circles radiating outward from a common point. The data can also be plotted on the north side of a semi-circle with equally graphic effect.

Strike histograms (frequency diagrams).--The intervals are plotted along the y-axis and the number (or percentage) of joints occurring within each 5° (or 10°) interval is plotted on the x-axis of an x-y plot.

The advantage of two-dimensional plots is that dominant or preferred joint set orientations can be readily recognized at the high-frequency peaks. The disadvantage is that a given peak can mask two sets of joints of distinctly different inclination and/or dip direction.

APPENDIX 5

A COMPARISON OF ELEVEN HARDNESS CLASSIFICATIONS FOR INTACT ROCK



APPENDIX 6

DATA SHEETS

Rock Description Data Sheets (3 sheets)

Line Survey Data Sheets (2 Sheets)

Discontinuity Survey Data Sheets (2 sheets)

ROCK DESCRIPTION DATA SHEETS

Sheet 1 of 3

GENERAL INFORMATION

Watershed Name: ____________ Structure Site Number: ____________ State: ________

Investigator: ____________________ Title: ____________ Date: ________

Type of Investigation, Check One:
___ Reconnaissance
___ Preliminary
___ Detailed/Design
___ As-built/Construction
___ Spillway Performance

Intensity of Investigation:
___ Subjective Survey
___ Objective Survey

Photograph/Slide Numbers: ____________

ROCK UNIT IDENTIFICATION

1. Rock Type Name or Alpha-numeric Designation: ____________ Code No. (from Table on sheet 2): ___ ___

2. Location (show on geol. map/sketch): Station ______ Offset (lt) ______ Offset (rt) ______ Elevation ________

3. Locality Type (check one): Natural Exposure ____ Excavated Channel Side Slope ____ Floor of Spillway ____

ROCK MATERIAL PROPERTIES

TABLE 1. Color (choose from up to 3 columns for selected condition below):

_____	_____	_____	Dry
_____	_____	_____	Wet
_____	_____	_____	Fresh
_____	_____	_____	Altered
light		white	
dark	yellowish	yellow	
	buff	buff	
	orangish	orange	
	brownish	brown	
	pinkish	pink	
	reddish	red	
	bluish	blue	
	purplish	purple	
	olive	olive	
	greyish	grey	
		black	

TABLE 2. Grain Size (for sedimentary and pyroclastic rocks), check one below:

Descriptor	Grain Size (mm/ sieve size)	
Very Coarse	> 75 mm/ 3 in. (cobble-size+)	____
Coarse	4.75 - 75 mm/ #4 - 3 in. (gravel-size)	____
Medium	0.075 - 4.75 mm/ #200 - #4 (sand-size)	____
Fine	0.005 - 0.075 mm (silt-size)	____
Very Fine	< 0.005 mm (clay-size)	____

TABLE 3. Texture (for ign. & cryst. meta. rocks), check one below:

Descriptor	Description of Texture	
Aphanitic	Components cannot be seen with naked eye	____
Crystalline	Composed of interlocking crystals	____
Glassy	Vitreous; without crystallization	____
Pegmatitic	Very coarsely crystalline (> 10 mm diameter)	____
Porphyritic	Large x'ls set in fine-grained ground mass	____

Other notes on rock material properties, such as unusual density, etc.:

____

____

____

____

____

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____

TABLE 1.—ROCK TYPE CLASSIFICATION

Genetic Group	Predominant Grain Size, mm (Sieve No.)	Detrital Sedimentary		Chemical/ Organic	Metamorphic		Pyroclastic	Igneous			
Usual Structure		Bedded		Bedded	Foliated	Massive	Bedded	Massive			
Composition		Grains of rock, quartz, feldspar, and clay minerals	At least 50 % of grains are of carbonate	Salts, carbonates, silica, carbonaceous	Quartz, feldspars, micas, dark minerals	Quartz, feldspars, micas, dark minerals, carbonates	At least 50 % of grains are of igneous rock	Quartz, feldspars, micas, dark minerals		Feldspar; dark minerals	Dark minerals
								Acid	Intermediate	Basic	Ultrabasic
Very Coarse-grained		Rudaceous: Grains are of rock fragments	LIMESTONE (undifferentiated) (21)	CLINKER (31)	TECTONIC BRECCIA (41); MIGMATITE (42)	METACONGLOMERATE (51)	Rounded grains: AGGLOMERATE (61)	PEGMATITE (71)			
Coarse-grained	75 (3") – 4.75 (4)	Rounded Grains: CONGLOMERATE (11); Angular grains: BRECCIA (12)	CALCIRUDITE (23)	SALINE ROCKS: Halite (32), Anhydrite (33), Gypsum (34)	GNEISS (43)	MARBLE (52)	Angular grains: VOLCANIC BRECCIA (62)	GRANITE (72)	DIORITE (81); GRANODIORITE (82)	GABBRO (91)	PYROXENITE (01)
Medium-grained	4.75 (4) – 0.074 (200)	Arenaceous: Grains are mainly mineral fragments: SANDSTONE (13); ARKOSE (14); GRAYWACKE (Argillaceous ss) (15)	CALCARENITE (24)	CALCAREOUS ROCKS	SCHIST (44); AMPHIBOLITE (45)	GRANULITE (53); QUARTZITE (54)	TUFF (63)	SYENITE (73)	ANORTHOSITE (83)	DIABASE (92)	PERIDOTITE (02)
Fine-grained	0.074 (200) – 0.005	Argillaceous or Lutaceous: MUDSTONE (16); SILTSTONE > 50 % fine-grained particles (18); MARLSTONE (22)	CALCI-SILTITE (25)	Limestone (35)	PHYLLITE (46)	HORNFELS (55)	Fine-grained TUFF (64)	APLITE (74)	MONZONITE (84); DACITE (85)	BASALT (93)	DUNITE (03)
Very Fine-grained	< 0.005	SHALE: fissile mudstone (17); CLAYSTONE > 50 % very fine grained particles (19)	CHALK (26); CALCILUTITE (27)	Dolomite (36)	MYLONITE (47); SLATE (48)		Very fine-grained TUFF (65)	RHYOLITE (75)	ANDESITE (86)		NEPHALINE-BASALT (04)
Glassy Amorphous				SILICEOUS ROCKS: Chert (37), Flint (38); CARBONACEOUS ROCKS: Lignite/ Coal (39)	ULTRAMYLONITE (49)		Welded TUFF (66); PUMICE (67)	VOLCANIC GLASSES: OBSIDIAN (76)	PITCHSTONE (87)	TACHYLYTE (94)	

Note: code number in parentheses is used in sheet 1 of 3, Rock Description Data Sheets

Sheet 3 of 3

Table 5: Earth Material Hardness Category, check one:

Earth Material Hardness Category	Uniaxial Compressive Strength (MPa)	Field Assessment Tests for Estimating Earth Material Hardness	Code	
Very soft soil*	< 0.04	Exudes between fingers when squeezed in hand. Easily penetrated several centimeters with fist.	1	___
Soft soil*	0.04 - 0.08	Easily molded with fingers. Pick head of geologic hammer can easily be pushed in to shaft of handle.	2	___
Firm soil*	0.08 - 0.15	Can be penetrated several centimeters by thumb with moderate pressure. Molded by fingers with some pressure.	3	___
Stiff soil*	0.15 - 0.30	Indented by thumb with great effort. Point of geologic pick can be pushed in up to 1 cm. Very difficult to mold with fingers. Can just be penetrated with hand spade.	4	___
Very stiff soil*	0.30 - 0.60	Indented only by thumbnail. Slight indentation produced by pushing point of geologic pick into material. Requires hand pick for excavation.	5	___
Very soft rock (or hard, soil-like material)	0.60 - 1.25	Can be scratched with fingernail. Slight indentation produced by light blow of point of geologic pick. Requires power tools for excavation. Can be peeled with a knife.	6	___
Soft rock	1.25 - 5.0	Hand-held specimen crumbles under firm blows with point of geological pick.	7	___
Moderately soft rock	5.0 - 12.5	Shallow indentations (1 to 3 mm) can be made by firm blows with point of geological pick. Can be peeled with pocket knife with difficulty.	8	___
Moderately hard rock	12.5 - 50.0	Cannot be scraped or peeled with pocket knife. Intact hand-held specimen can be broken with a single blow of hammer end of geologic pick. Can be distinctly scratched with a steel nail.	9	___
Hard rock	50.0 - 100.0	Intact hand-held specimen requires more than one hammer blow to break it. Can be faintly scratched with a steel nail.	10	___
Very hard rock	100.0 - 250.0	Intact specimen breaks only by repeated, heavy blows with geologic hammer. Cannot be scratched with a steel nail.	11	___
Extremely hard rock	> 250.0	Intact specimen can only be chipped, not broken, by repeated, heavy blows of a geological hammer.	12	___

Notes:

(1) Hardness category is based solely on hardness characteristics rather than geologic origin. For examples, a highly weathered shale may classify as Firm Soil, while a partially lithified, Recent soil may classify as Moderately Soft Rock. The transition, however, more commonly occurs in the 0.60 to 1.25 MPa range.

(2) Materials marked with (*) must be evaluated for hardness in the wet condition and are assumed to be cohesive.

(3) 1.0 Megapascal (MPa) equals approx. 145 pounds per square inch (psi) or 10.4 tons per square foot (tsf).

(4) Vane shear strength values are also applicable in the lower strength ranges.

TABLE 6. Test method used above, check one:

Field Assessment	___
Pocket Penetrometer	___
Schmidt Rebound Hammer	___
Point Load Test	___
Uniaxial Lab Test	___

TABLE 7. Secondary Cavities (void diameter); check type (s) if applicable:

Descriptor	
Pitted (1 - 10 mm)	___
Vuggy (11 - 100 mm)	___
Cavitied (> 100 mm)	___
Honeycombed	___
Vesicular	___

LINE SURVEY DATA SHEET

Sheet 1 of 2

ROCK MASS PROPERTIES

1. Line Survey to Determine Average Spacing of Joint Sets.

--Plot location of surveyed lines on a geologic evaluation map or sketch.

--Notes: For systematic joint sets:
1. Lines 1 and 2 are for the two most persistent, high-angle, intersecting joints.
2. Line 3 is for bedding plane partings or sheeting joints (the vertical axis).

--Notes: For apparently random fractures:
1. Line 1 is perpendicular to spillway flow direction.
2. Line 2 is parallel to spillway flow direction.
3. Line 3 is for bedding plane partings or sheeting joints (the vertical axis).

Survey Line (axis)	a	b	c	d	e	f
	Plunge of Line	Trend (Azim)	Line Length (Meters)	No. of Joints	Average Spacing d/c	Spacing Category
Line 1 (x)						
Line 2 (y)						
Line 3 (z)						

2. Spacing Categories (for column f above):

SPACING DESCRIPTORS		Spacing	Category
Bedding Plane Partings	Joint Sets	(Meters)	
Massive/unstratified	Extremely wide	> 6.000	1
Very thick-bedded	Very wide	2.000 - 6.000	2
Thick-bedded	Wide	0.600 - 2.000	3
Medium bedded	Mod. wide	0.200 - 0.600	4
Thin-bedded	Mod. close	0.060 - 0.200	5
Very thin-bedded	Close	0.020 - 0.060	6
Laminated	Very close	0.006 - 0.020	7
Thinly laminated	Shattered	0.002 - 0.006	8
Fissile	Fissured	< 0.002	9

4. Discrete Rock Particle Mean Diameter = $\sqrt[3]{e_x e_y e_z}$ = ____________ meters
(use values in column e)

5. Other observations/notes on rock mass properties:

____

____

____

____

____

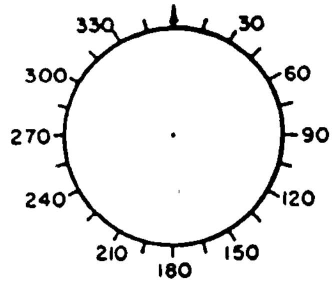
____

____

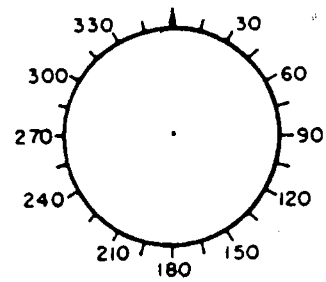
____

SKETCH MAP OF EMERGENCY SPILLWAY

--On both circles below, plot azimuths of spillway flow direction using an arrow.
--On left circle, plot strike and dip of rock. On right circle, plot trends and plunges of major joint sets.
--Indicate approximate location of dam (i.e., left side or right side).



Spillway Flow
vs.
Strike and Dip



Spillway Flow
vs.
Joint Set Orientations

DISCONTINUITY SURVEY DATA SHEETS

Notes:
1. Assign each discontinuity an ID number and show location on geologic evaluation map or sketch.
2. Use codes numbers from the following tables and enter data on the form at the bottom of this sheet and on Sheet 2 of 2.
3. Use code from Table 5, Rock Description Data Sheets for classifying compressive strength of infilling.
4. Classify infilling according to ASTM D-2488 (USCS), record soil symbols on data sheet.

TABLE A

Discontinuity Category	Code
I. STRATIGRAPHIC	
A. Lithosome	
* Blanket................	1
* Tongue.................	2
* Shoestring............	3
* Lens..................	4
* Slump feature.........	5
B. Unconformity.............	6
II. STRUCTURAL	
A. Plastic Deformation	
* Folded rock............	7
* Foliation	
- schistosity........	8
- gneissosity........	9
* Banded rock...........	10
B. Fracture Deformation	
* Random fracture.......	11
* Systematic joint set..	12
* Bedding plane parting	
- uniformly bedded ..	13
- cross-bedded........	14
- rhythmic bedding....	15
- interfingered.......	16
- graded bedding......	17
- current bedding.....	18
* Sheeting joint.........	19
* Slaty cleavage.........	20
* Fault..................	21
* Other (put in notes)...	22

TABLE B

Joint Persistence Category	Trace Length (meters)	Code
Very low	< 1	1
Low	1 - 3	2
Medium	3 - 10	3
High	10 - 20	4
Very high	> 20	5

TABLE C

Joint End Category	End 1	End 2
Joint end extends beyond the exposure area.	x b	x b
Joint end terminates in solid rock inside exposure area.	t r	t r
Joint end terminates against another joint.	t j	t j

TABLE D

Aperture Category	Width Range (mm)	Code
Wide	> 200	1
Moderately wide	60 - 200	2
Moderately narrow	20 - 60	3
Narrow	6 - 20	4
Very narrow	2 - 6	5
Extremely narrow (hairline)	> 0 - 2	6

TABLE E

Nature of Joint Infilling	Code
Clean, open joint; no infilling present.	1
Non-plastic silt (PI > 10), sand, or gravel; with or without crushed rock.	2
Inactive clay or clay matrix; with or without crushed rock.	3
Swelling clay or clay matrix; with or without crushed rock.	4
Chlorite; talc; mica; serpentine; other sheet silicate; graphite; gypsum. Specify type in notes.	5

TABLE F

Descriptor	Weathering Condition of Joint Face Rock Material	Code
Fresh	No sign of weathering.	1
Discolored	Iron-stained or discolored, but otherwise unweathered.	2
Disintegrated	Physically disintegrated to a soil condition with original fabric still intact. Material is friable and mineral grains are not decomposed.	3
Decomposed	Chemically altered to a soil condition with original fabric still intact. Some or all mineral grains are decomposed.	4

TABLE #	A	Measurement				B	C		D	E	5	D-2488	F
Discon. ID No.	Discon. Type No.	Trend (Azim)	Dip	Dip Direction	Joint Perst. (m)	Joint Persist. Code	End 1 Code	End 2 Code	Aper. Width Code	Nature Infill. Code	Strength Infill. Code	Infill. Classif. (USCS)	Joint Wea. Code
1													
2													
3													
4													
5													

CONTINUATION SHEET

TABLE #	A	Measurement				B	C		D	E	5	D-2488	F
Discon. ID No.	Discon. Type No.	Trend (Azim)	Dip	Dip Direction	Joint Perst. (m)	Joint Persist. Code	End 1 Code	End 2 Code	Aper. Width Code	Nature Infill. Code	Strength Infill. Code	Infill. Classif. (USCS)	Joint Wea. Code

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